To the Right Honourable Peter Walker, M.B.E., M.P.,
Secretary of State for the Environment.

Sir,

1. Our first interim report, submitted in October 1965*, described the background to the setting up of the Working Party and gave an account of our activities from our formation in June 1964 up to that time. Our second report, submitted in May 1967, included a recommendation that a major programme of experimental research be carried out so that we might offer detailed advice on the structural design of sewers. We now have the honour to submit our third report.

2. We have met as a full Working Party on thirty-seven occasions. Since our last report we have visited construction sites and pipe manufacturing works of particular interest. Our research team leader has visited many laboratories to advise us on the best methods of carrying out our own research programme. Members of the Working Party have attended regular meetings of the panel directing the research. Our sub-committees have held sixty-five meetings.

3. We are dividing this report into three main sections. The first continues our considerations of the practical design and construction of sewers which formed part of our second report. The second section deals with foreign practice, and the third with the programme of research which we have been authorised to carry out. Finally the report concludes with a review of the position. It is emphasised that the three main sections are closely related. Our advice on design and construction depends to a considerable extent on research. As a result of our investigation of foreign practice, our own research and recommendations will be able to take cognizance of world wide experience. Our research is still at an early stage and we are not yet able to elaborate the recommendations on structural design given in our second report. The urgent need for information on our research and advice on its application is of course appreciated.

4. A revised edition of British Standard Code of Practice 2005, *Sewerage* was published in December 1968. The code outlines the rational method of structural design and details the traditional method. The timing of the publication of the Code prevented the inclusion of the recommendations contained in our second report, but the Code indicated that its next revision would deal with the subject more comprehensively.

5. We are pleased that *Simplified tables of external loads on buried pipelines*, replacing National Building Study Special Report 32, was published in 1970.

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*Published in 1966.

The new publication is based on the criteria we suggested in paragraph 235 of our second report. It is likewise gratifying that many design tables issued by pipe manufacturing associations have also been brought into line with our recommendations.

6. During the past few months everyone has been urged to consider environmental pollution and warned of the dire consequences of neglecting our heritage. The common forms of pollution of the atmosphere, rivers and land are usually obvious to all with a discerning eye. Pollution due to faulty sewers may not be so readily apparent but broken pipes, blockages or slight structural defects can result in leakage leading to pollution of the surrounding ground, nearby watercourses and underground water supplies. Good sewer design can contribute to the prevention of pollution. Money spent on designing a sewer so that it is structurally sound is a good investment, in that the life of the sewer will be increased and pollution prevented.

Section A. The design and construction of sewers

Manholes, sewer lines and connections to sewers

7. In our second interim report we expressed the opinion that sewer lines, manhole spacing and sewer maintenance were inter-related. The limited but divergent information available at that time led us to recommend that the Department's Form K29 requirements for sewer lines and manhole spacing should not be changed, except that no objection should be raised to horizontal curves of reasonable radius on sewers in which men can work. In order to satisfy ourselves that this recommendation was supported by practical experience we decided to consider the subject in more detail and seek further information from a number of engineers responsible for the design, construction and maintenance of sewers.

The location and spacing of manholes

8. At present manholes are constructed at summits, changes of diameter, direction and gradient and where sewers join. Manholes are provided primarily for the purpose of access to sewers for inspection and maintenance, and their presence enables a sewer and any blockages to be easily located. Manholes are also used for rodent control, television surveys, flow measurement and tracing illegal discharges. They may be used to ventilate sewers, but are not essential for the conveyance of sewage. It appears that rodent control, particularly in the older urban areas, requires the most frequent and easy access to a sewer and therefore the presence of a manhole.

9. The question to which we have addressed ourselves is whether the present criteria for manhole spacing are reasonable; whether in fact manholes are essential at all summits, changes of diameter, direction and gradient—however slight—and where sewers join.

10. The average cost of manholes amounts to approximately 16% of the cost of sewerage systems. Since the total amount spent each year on sewerage and ancillary drainage in this country is believed to be of the order of £200 million the cost of manholes and inspection chambers could, on this basis, be in the neighbourhood of £32 million. This is a large sum and it could be that purely in terms of cost the saving by eliminating manholes at some of the locations listed in the previous paragraph could be far greater than the expense of excavating down to sewers where blockages occur. However, one must not overlook that the time taken to excavate to a blockage might cause inconvenience and increase the danger to the health of occupants of properties draining to the sewer.

Questionnaire on manholes, blockages and connections to sewers

11. In order to obtain information on manhole design, spacing, blockages and the connections of drains to sewers we sent a questionnaire to a number of consulting engineers and local authority engineers. The questionnaire was limited to foul sewers up to and including 9 in diameter. It asked the engineers to provide information on:

(a) the spacing of manholes on 9 in diameter and smaller sewers;

(b) the construction of manholes and their cost;

(c) the occurrence of blockages and the methods used to clear these blockages; and

(d) the methods used to form drain connections to sewers.

Paragraphs 12 to 17 below summarise the thirty-three replies received from local authority engineers and consulting engineers covering a cross section of county boroughs, urban districts and rural districts*.

12. The authorities had on average 54 yards of sewer per manhole. Only five authorities had manholes at distances greater than the maximum of 120 yards suggested on the Department's Form K29. Most of the manholes at greater spacing were on old sewers and some authorities were constructing additional manholes to reduce these spacings. It appeared that over 80% of all manholes were constructed of pre-cast concrete sections. Pre-cast concrete manhole chambers were usually 42 in diameter or larger, while those of brick varied from 2 ft 9 in by 2 ft 6 in to 4 ft 6 in square. Shafts usually had a minimum width of 27 in. Only one of the authorities used thick-wall pre-cast concrete manhole sections without an in-situ concrete surround and it limited this type of construction to manholes above ground water table. Brick manholes appeared to be more expensive than standard concrete manholes, especially if they exceeded the minimum dimensions. The cost of manholes decreased from about 20% to about 10% of the cost of a scheme as the spacing increased from 60 to 90 yards. Most engineers provided some form of flexibility in the sewer lines at or near manholes by using short flexibly jointed pipes. Few engineers stated that they undertook regular routine cleaning and hence few reported that manholes were used for this purpose.

13. It is difficult to summarise the replies on occurrence of blockages. It appears that about half of the reported blockages occurred at known trouble spots. Sewer blockages occurred at the rate of approximately one per year per sixty-four lengths between manholes. If haphazard blockages only are considered they occurred at about one per year per hundred lengths of sewer. Poor construction, bad joints, structural damage, backdrops and builders' debris were claimed to be the principal causes of blockages.

14. Blockages were normally cleared by manually operated rodding. Other means in order of preference were jetting, winching and mechanically operated rodding. In less than 5% of the blockages was excavation necessary to clear them. Both cane and steel rods were in general use; the former were preferred for short lengths or where grease was encountered and the latter were considered essential for longer lengths. About a third of the authorities had jetting equip-

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*Where inquiries were made or information was supplied in imperial units these have been used in this report.

ment and were satisfied with its effectiveness. Winching equipment was also held by a third of the authorities. Whilst those who held winching equipment thought it was effective, power operated equipment was preferred to manual equipment. Many authorities employed specialist contractors for power winching or power jetting but not with any great frequency.

15. The use of television surveys was increasing. Where there were frequent blockages nearly half the authorities used a television survey to ascertain the cause.

16. Nearly all authorities permitted saddles up to 6 in diameter on all sizes of main sewer. Connections were also constructed by inserting junction pipes or using joinders. Most authorities required the length of the lateral before entering the sewer to be laid at a gradient of 1 in 1 where this was practicable and nearly all authorities required entry to the main sewer to be by a 45° angle branch or saddle. Six inch concrete surround was sometimes required at junctions.

17. K29 requirements for concrete bed and haunch and surround were usually followed for that part of a drain from the junction to the curtilage of the property. One authority required trenches to be backfilled with lean concrete where drains were constructed in the carriageway and another required concrete, wet mix macadam or crusher run aggregate where drains were deep.

Curvature of sewers

18. In our second report we noted that it was not uncommon practice in the United States to lay sewers on horizontal and vertical curves. In some areas of that country it is contended that curves on sewers present no significant maintenance problems and allow manhole spacing to be increased. We saw no objection to horizontal curves of reasonable radius on sewers in which men could work. It was appreciated that this comment did not cover all facets of the problem and that further consideration should be given to the subject.

Questionnaire on curvature

19. As there was little information on which to base a recommendation on the amount of curvature which should be accepted, a separate questionnaire was sent to a number of engineers to sewerage authorities and consulting engineers, seeking information on the construction and operation of curved sewers of all sizes and their views on the subject generally. The questionnaire asked for information on the sizes and types of sewer which were permitted to be constructed with curvature, curved sewers which had operated unsatisfactorily and provisions made for locating curved sewers. The replies to this questionnaire indicated that curvature was mainly found on old sewers and that there had been few blockages. Twenty-one of thirty-five replies indicated that the engineer had some sewers laid with horizontal curves and eight of the thirty-five had some sewers laid with vertical curves. Twenty-nine engineers did not permit sewers up to 9 in diameter to be constructed with curves and of these twenty-one engineers did not permit sewers up to 3 ft diameter to be constructed with curvature. Only ten engineers did not permit sewers 3 ft or more in diameter to be constructed with curves. Engineers only constructed curved sewers if there was a definite advantage such as the avoidance of other services, a reduction in the

number of manholes, considerable financial saving or reduced interference with traffic.

20. Many engineers pointed out that the location of curved sewers depended on surveys and record plans and objected to them because they were difficult to find. They considered that curved sewers were harder to inspect, that they restricted the use of television surveys, that they were difficult to clean with a power winch and that there was a risk of drain rod fittings being trapped in enlarged joints. Some considered that there was an increased risk of blockage on sharp bends, particularly on small diameter sewers. Some engineers believed that curved sewers sterilised a greater area of land and were more difficult to construct and to avoid in future work. Some claimed that the increase in length between manholes could make rodding impossible and would not necessarily significantly reduce the number of manholes.

The eradication of sewer rats in relation to manhole spacing and other aspects of sewer design

21. We have been asked by the Infestation Control Laboratory of the Ministry of Agriculture, Fisheries and Food to consider the need to design sewers so that they do not harbour rats. Sewers and drains support permanent rat infestations and give rats relatively free movement through urban areas. Local authorities are required by the Prevention of Damage by Pests Act 1949 to inspect for and destroy rats in their sewers.

22. Sewer rats spread, through their urine, the causative organisms of leptospirosis. They are a reservoir from which surface infestations arise, thereby leading to health hazards to the human population and causing economic loss. The tunnelling operations of rats, as they escape through structural defects in sewers, may undermine pipes and services and lead to structural failure.

23. A soundly constructed sewerage system will not harbour rats, since the continual flow of sewage deprives them of the secure nesting sites they need. The presence of rats in some newly constructed systems indicates that precautions are not always as thorough as they should be. Accidental damage and poor maintenance can lead to deterioration of a soundly constructed system so that it becomes infested. Any new sewerage system should be designed, as far as possible and bearing all other relevant factors in mind, to prevent rat infestation and to enable effective action to be taken against infestation should it occur. Pipe ends should never be left open but should be closed with stoppers and sealed until required. The connection to the public sewer should be done in one operation but if this cannot be completed in one day the opening in the sewer should be closed at night to prevent the movement of rats.

24. Sewer rats are controlled or eradicated by poison-baiting. In sewers baiting sites are usually restricted to inspection chambers and manholes but since there is no certainty that rats will visit these the control of infestation is slower and less efficient than on the surface of the ground. If the spacing of chambers were increased much beyond 100 yards we are advised that this would be detrimental to rat control. Baiting is made easier if chambers are designed to have a benching that is almost flat so that bait can be laid just above the normal level of the sewage.

25. In addition to eradication, steps should be taken to prevent infestation by rats. Where areas are being redeveloped many lengths of sewer are no longer used and provide ideal harbourage for rats. It is important that unused pipes should be sealed off at the sewer and the remainder removed or filled with concrete or other suitable material such as pulverised fuel ash. Stringent control should be exercised over the sealing of disused sewers and drains. Rats can also gain access to sewers via outfalls into watercourses and these should be fitted with hinged flap valves on vertical walls designed to prevent rat access.

Comments on manholes, sewer lines and connections to sewers

(*a*) *General*

26. The answers to the questionnaires referred to in paragraphs 11 and 19 are useful as a general guide, but do not provide sufficient information on which to base clear and unequivocal advice on these aspects of the design of sewers, the optimum spacing and best methods of construction of manholes, nor indeed whether manholes are essential in many of the situations where they are now provided.

27. Blockages seem to be fairly infrequent. Although the causes of blockages are not established in great detail, many occur at known trouble spots particularly on flat gradients. It is thought that more blockages occur at house connection junctions without manholes than elsewhere. Few blockages occur at manholes. Many result from poor construction and emphasise the need for good and adequate supervision during construction generally and at joints and flat gradients in particular.

(*b*) *Manhole spacing and construction*

28. Existing equipment for clearing blockages in sewers appears to be effective up to about 100 to 120 yards. It might be thought that this governs to a large extent the spacing of manholes, but it is probable that the manufacturers of sewer cleaning equipment could improve their products or produce entirely new methods of sewer cleaning to deal effectively with greater lengths.

29. With the present basis of design every sewerage authority should be equipped with steel rods which are effective up to 80 yards. In order to avoid difficulties in working at the limit of capability of the equipment the continuance of the present maximum spacing of 120 yards is in this respect reasonable. The use of 120 yards for the spacing of manholes, although above the 100 yards desirable for rodent control, should not make eradication of sewer rats particularly difficult. Greater distances between manholes would increase the likelihood of overflow occurring at inspection chambers on private property in the event of a blockage, whereas with shorter spacing such an overflow will usually be confined to the nearest manhole on the sewer.

30. On the basis of information now available we confirm the views expressed in our second report that no change should be made at the present time in the Department's requirements relating to the spacing of manholes as set out in form K29. Nevertheless we refer in paragraph 36 to the need for systematic collection of data regarding the use of manholes.

31. Precast manholes are largely superseding brick manholes and it is thought that this trend is likely to continue on the smaller diameter sewers. We do not

see any special reason for changing the minimum diameter of the chamber of a precast concrete manhole from the existing 42 in. A larger diameter chamber would improve working conditions but would incur additional cost. An increase in diameter might be necessary if the spacing of manholes were increased. Larger chambers are in any case used on large sewers. The 27 in diameter shaft is regarded as an acceptable minimum, although there is a tendency among some engineers to prefer a diameter of 30 in. The cost of some concrete manholes could be reduced if they were provided with a mechanical watertight joint between the sections which would enable the concrete surround to be omitted. Where it is considered that a benching just above the normal sewage level could become too slippery for an operator to work on safely due to the occasional lodgment of sewage, a small flat surface, not less than 12 in by 8 in should be provided just above the benching to enable sewer rat bait to be laid.

32. Flexibility of sewers at manholes is considered essential.

(*c*) *Connections to sewers*

33. The way in which connections to sewers should be made has been considered at length. Connections can take many forms and in the following paragraphs we enunciate the principles which we consider most important.

i. Although paragraph 132 of our second report indicated a trend towards the use of 90° junctions in the United States, we prefer Y-junctions because of the smoother hydraulic path, the lower risk of blockage and the reduced vulnerability to damage of the main sewer from rodding through the branch.

ii. Ideally a connection to a sewer should be constructed so that none of its weight is transmitted to the sewer whether this be a rigid pipeline, a flexible line of rigid pipes or a line of flexible pipes. This is especially important in cases where the pipes are bedded on granular material, which should not be disturbed, and where it is desirable not to destroy the flexibility of the lines by inserting, possibly at frequent intervals, heavy blocks of concrete. The aim should be for the weight of the connection to be carried by the ground and that the last two joints, at least, should be flexible. Where the connection is vertical, though this should be avoided if possible, it is particularly important that it should come down beside and not on top of the sewer and that there should be room for flexible joints to be inserted between the vertical pipe and the sewer.

iii. Special protective measures should be considered for very shallow connections liable to physical disturbance or heavy loading, e.g. the use of concrete surround with 'cleavage planes' for connections with less than 4 ft of cover in highways. It is desirable, however, that a pipe laid on a granular bed should have a gradient not steeper than 1 in 6 as the granular fill may be unstable at greater slopes. It may in some cases be possible for the lowest two or three pipes to be laid on granular fill at a gradient less steep than 1 in 6 and for the remainder of the connection to be laid at a steeper slope on or surrounded with lean concrete.

iv. Where frequent connections have to be made to a deep sewer the alternative of shallow rider sewers to take the connections should be examined as this may be less costly.

v. Connections made with saddles should not be located at the top of the pipe but just above the springing. Saddles, however, are not an ideal solution as it is virtually impossible to cut an accurate hole in a pipe and joint the saddle without some irregularity in the internal profile of the sewer. Junctions should, wherever feasible, be provided for future development.

(*d*) *The laying of sewers on curves*

34. Whilst it is desirable for sewers to be laid in straight lines between manholes, it is advantageous in some situations for sewers to be laid in curves. The objections to curved sewers decrease as the size of the sewer and the radius of the curve increase. No engineer likes curved sewers 9 in diameter or smaller but there are few objections to sewers being laid on a curve if they can be entered and repaired by a man working from inside the sewer. There are no hydraulic objections to the construction of larger sewers on curves. It is our view that the minimum diameter for a sewer to be constructed on a curve is about 36 in but we would not preclude consideration of curves on sewers down to 30 in diameter if necessary. In arriving at this conclusion we have not overlooked the indirect benefit from manholes on straight sewers in that they discourage the location of other services above a sewer.

35. It is most desirable for a manhole to be located near a bend but opinions differ on whether a manhole should be located above or below the bend. We feel that it is preferable for bends to be on the downstream side of a manhole to facilitate rodding. Whilst manholes are very useful when locating the precise position of a curved sewer and can save staff time on maintaining a sewer it does not necessarily follow that they are the most economical means of providing a permanent marker of its location.

(*e*) *The need for more information*

36. We consider that, in order that wider authoritative information may be available on the spacing of manholes, sewerage authorities should be asked to record over a period of 10 to 15 years information on the uses and frequency of use of manholes. The present criteria for the location of manholes could be tested by the construction of a sewerage system in which selected manholes were omitted. The consequences of surcharge affecting premises, in the absence of a manhole in the street, would have to be borne in mind. Should it prove possible to reduce the positions where manholes are now traditionally built, it would be necessary to devise some alternative means for the easy location of sewers. There is a dearth of information on the value of laying sewers with curves, and some thought should be given to the construction of a sewerage system with curves of varying radii and observing it in use.

Use of granular bedding

37. We have received reports that granular bedding has formed a drainage channel in the bottom of the trench and that in some instances ground water has flowed in such quantities and at such pressures that it has been observed bubbling from the surface of the ground at low points, thus confirming the comment in paragraph 147 of our second report that waterstops may be necessary in certain ground conditions. In our research into overseas practice in section B of this report we have noted the use of finer materials for bedding pipes in other countries. At this stage we do not have sufficient information to depart from the gradings mentioned in the *Note of Guidance on Practical Considerations in the*

Structural Design and in the Construction of Small-diameter Sewers and Drains (obtainable from HMSO Code No. 75–194) but propose that our research team should investigate the problem at an appropriate opportunity.

Pipe joints

38. Since our second report we have been pleased to note the increasing use of mechanical joints* for rigid pipe sewers. Large quantities of plain ended small diameter clay pipes are also being produced for use with a polypropylene sleeve and have similar advantages to those of mechanical joints for socket and spigot pipes. On the other hand, we are informed that there is still a considerable demand for pipes with rigid joints from those who are unaware of or have not acted on our recommendations that mechanical joints should be used for rigid pipe sewers.

39. We regret that our reports do not appear to have reached the large number of architects, engineers, quantity surveyors, contractors, builders, building control officers and builders' merchants who are still using rigid jointed pipes for sewers and drains. It is extremely difficult to reach all those associated with the industry and we take this opportunity to ask all Government Departments, Institutions, Associations and Technical Journals to do whatever they can to encourage the use of mechanical joints except in the few cases where they are inappropriate.

40. In our second report we recommended that where loan sanction is required the Department should consider making mandatory the use of mechanical joints with rigid pipes. We recognised that such a move could involve changes in manufacturing techniques and plant and that a period should elapse before the change was put into effect. It would also be essential for pipes with mechanical joints to be available in large quantities and we therefore indicated that 5 years should elapse before such a step should be considered. This would have been in May 1972 but we understand that the clay pipe industry may not have sufficient manufacturing capacity of mechanically jointed pipes by this date.

41. We believe nonetheless that there could be within a relatively short period sufficient rigid pipes with mechanical joints to meet the demand if rigid joints with rigid pipes were no longer approved for loan sanction purposes. We consider that as soon as pipes are available in such quantities the Department should amend its Form K29 requirements accordingly. In any event we would urge that, in the absence of any major change in circumstances, such an amendment should not be delayed longer than 2 years beyond the 5 year period from 1967 which we originally suggested in our second report.

42. However, such a step on its own is unlikely to have a very large impact on the use of rigid jointed pipes as we believe that most K29 schemes already consist of mechanically jointed pipes. The only way, therefore, to make a further appreciable reduction in the use of rigid joints is to approach directly or indirectly, those who are responsible for projects which do not have to be submitted to the Department for approval. Nearly all these schemes are subject in England and Wales to The Building Regulations 1965, in Scotland to The Building Standards (Scotland) (Consolidation) Regulations 1970 and to inspection by local authority

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*As in our second report we continue the use of the term mechanical joints for joints with factory made jointing material. These are often called flexible joints.

building control officers. The Building Regulations require the joints of drains or private sewers to be formed in such a manner that they remain watertight under all working conditions including any differential movement as between the pipe and the ground or any structure through or under which it passes. As there are few circumstances where the possibility of differential settlement does not exist, more stringent interpretation of the Regulations could result in greater use of mechanical joints. The Scottish Building Standards do not refer specifically to differential settlement but they do require regard to be paid to the nature of the ground through which the drain passes. Although we are of the opinion that consideration should be given to amending the content of the regulations regarding the jointing of drainage pipelines to increase the use of mechanical joints, this could be deferred for up to 12 months after the amendments of the K29 requirements outlined in the previous paragraph to reduce the impact of too sudden a change in demand for such pipes.

Dimensional standardisation

43. Our aim has been to achieve a balance between good construction and reasonable cost. The ideal sewer is not necessarily the cheapest nor the one that lasts longest. Quality and cost usually conflict. In our previous reports we have considered the desirability of reducing the range of pipe sizes and strength classifications and of limiting tolerances. In conjunction with their metrication programme, the British Standards Institution, bearing in mind the advantage of variety reduction and dimensional co-ordination, have set up a committee to select preferred sizes of pipes. Some British Standards are being revised to show certain sizes of pipes as non-preferred or not always available. Where the demand for the non-preferred size is small it is likely to be deleted from future editions of the standard. If some of the non-preferred sizes are deleted the difference between the remaining sizes, particularly with the substantial dimensional tolerances now permitted in some cases, is likely to be considerable and to raise the total cost of constructing some sewers. Size-variety reduction may reduce pipe costs but it is very doubtful if the savings will be sufficient to cover the additional excavation and bedding material for the next larger size of pipe. Whilst we are not opposed to variety reduction we cannot support it being taken to such lengths that it involves additional cost without benefit to the purchaser. The problem is more an economic one than a technical one, and it is probable that the demand for certain non-preferred pipes will be sufficient for them to be retained by some if not all manufacturers. It is important that the interests of the purchaser should not be overlooked.

44. The reduction of the number of strength classifications does not appear to be against the interests of the consumer. The deletion of a strength classification may result in the use of a slightly dearer pipe of the same nominal diameter but it does not involve any other additional costs. Strength-variety reduction might give sufficient benefit to the manufacturers for the additional cost to be nominal, or even disappear.

The structural design of lines of flexible pipes

45. The use of flexible pipes, particularly plastics pipes, is increasing but their design is still based largely on limited practical experience. Such a situation is unsatisfactory, especially with a material which is subject to creep effects and

does not strengthen with age. Fortunately the problem is appreciated by many of those connected with the use of plastics pipes. The manufacturers, the Agrément Board* and the former Ministry of Public Building and Works have initiated research into some of the properties of plastics pipes, and we hope that our own research will make a valuable contribution. There are, however, many variables and it is likely to be some time before the design and construction of sewers in plastics is based on scientific evidence. In the meantime it is hoped that the manufacturers will adopt adequate pipe thicknesses and so maintain a sound reputation for their products. We are aware of experiments carried out on the Continent and will take all reasonable steps to obtain such information on these as is likely to assist us in advising on the use of plastics pipes for underground sewers.

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*The Agrément Board is an independent organisation set up by the former Minister of Public Building and Works to give authoritative technical assessments of new building products.

Section B. Overseas practice

Need to obtain information on overseas practice

46. Sewerage design and construction are not uniform throughout the world as they are affected by variations of temperature, soil conditions, acidity of sewage, traffic loading, availability of materials and methods of construction. Nevertheless, the need is universal to construct sewers at the most economic cost so that they convey sewage satisfactorily, are structurally sound and require the minimum of maintenance. The designer, wherever he works, has the same objects to achieve and similar problems to overcome.

47. The theory of structural design has for many years been based on the work started by Marston in Iowa during the early part of the century. Research workers in all parts of the world have examined this work and used it as a basis for their own reasoning. They are generally agreed that an exchange of the results of their work is to the advantage of the majority in achieving the common aim of the best design.

48. Similarly, materials available and means of construction are not so varied that the methods used in one country cannot be compared with those in another. Whilst economic factors such as the availability of labour have an impact on design, we thought that the basic purpose of good sewerage design and construction was so general that a survey of overseas practice would be of considerable advantage. It would be imprudent to accept that our own methods of design, construction and research were necessarily the best without first enquiring what methods of construction were used in other parts of the world and deliberating on any variations with a view to recommending whether any improvement could be achieved by modifying our methods.

49. We therefore undertook an investigation into overseas practice with two basic aims:

(a) to ascertain the methods of constructing sewers in other countries and

(b) to seek information on research into sewerage design being carried out in other countries.

As a result of this investigation our own construction and research could take into consideration the wider knowledge obtained from and the opinions held in other parts of the world.

50. Persons known to have considerable knowledge of sewerage in overseas countries are usually those who have written a paper on a particular aspect of

the subject or are active members of an international or trade organisation having an interest in the manufacture of a particular material. Many such persons were contacted, and they provided most valuable reports on particular aspects of work in foreign countries. The information, however, tended to be of an academic and specialist nature and did not provide a full or balanced picture of sewerage overseas.

51. In order, therefore, to obtain more general knowledge, the London embassies of many countries were asked to provide the names and addresses of organisations and persons who could provide information on sewerage in their countries. The Institution of Municipal Engineers furnished addresses of secretaries of the member countries of the International Federation of Municipal Engineers. The Clay Pipe Development Association Limited supplied the addresses of many persons known to be associated with sewerage design and construction, many of whom were not connected with the clay pipe industry.

52. Letters seeking information on sewerage design, construction and research were sent in French, Italian, German, Danish, Spanish or English, as appropriate, to all who had been nominated. A large number of the overseas correspondents provided information in varying amount of detail on the design and construction normally adopted in their country and enclosed books, plans and copies of standards used.

53. One large city provided 30 detailed plans of its own sewerage systems with books on their construction. Much of the information was in a foreign language and had to be translated before it could be used. Whilst we are most grateful to all who have helped in this survey, we particularly appreciate the assistance of the consulting engineers in Holland who provided us with a detailed report in English on sewerage design in that country. We also received lengthy extracts, written in excellent English, from magazines describing the unique sewerage systems of Vienna and Amsterdam. A miniature library, of a type not hitherto available to us, was collected in a very short time.

54. References provided by the foreign correspondents were followed up and many overseas standards were borrowed from the library of the British Standards Institution. Further information has been obtained from books, published papers, magazine articles and personal contacts. The Clay Pipe Development Association Ltd. provided valuable information on sewerage in Czechoslovakia and have kindly granted their permission to incorporate this in the report.

Editing of information

55. Since the collecting of information on sewerage did not justify the world wide tour of an engineer accompanied by interpreters, it has been necessary to obtain most of the information by correspondence. Whilst every effort has been made to translate the information accurately the difficulties of the professional translator working on technical documents are apparent if one considers our use of the terms earthenware, stoneware and clayware for what is virtually the same material. A translator cannot be expected to know that there is little difference between a 'stone' pipe and a 'clay' pipe. It is apposite to comment that the older terms 'earthenware' and 'stoneware' are still widely used overseas. Similar anomalies exist in other languages, so that accurate translation of technical information is not an easy task.

56. The information has varied widely in scope and content. The language hurdle has resulted in greater information from the countries speaking or having a knowledge of English than from the remainder. The information has also varied in content due to variation in appreciation of the task, the correspondents' enthusiasm and the information available.

57. Short reports of the main features of sewerage design in many countries have been compiled and are given in an appendix to this report. They are grouped generally by continents and sub-continents and relate to the following countries:

Europe: Austria, Czechoslovakia, Denmark, Finland, France, Holland, Ireland (Republic of), Italy, Russia, Spain, Sweden, Switzerland, West Germany.

Middle East: Israel.

Australasia: Australia, New Zealand.

North America: Canada, United States.

South America: Argentine, Brazil, Colombia.

West Indies: Jamaica, Trinidad.

Federation of Malaysia: Malaysia, Singapore.

Central Africa: Zambia.

West Africa: Ghana.

Japan and Hong Kong: Hong Kong, Japan.

India.

58. The reports on individual countries were compiled as the result of general requests for information to government departments, municipal engineers, consulting engineers and research workers. Some countries follow national standards and codes of practice, while in others considerable variation occurs from one part of the country to another. Design and construction details adopted nationally have been regarded as more important than practice adopted by individuals. Nevertheless, the latter have not been overlooked since research and development frequently commence in a small way and may result in important changes.

59. As previously stated the information available on each country has varied tremendously in scope. It should not be thought that the countries that have provided limited information are more backward, nor conversely should it be assumed that those which have co-operated and provided extensive information are necessarily more advanced. Some countries have failed to provide any information. It must also be stressed that the reports have been based on information from a limited number of sources in each country and particularly where there are variations within the country the report may not be typical.

60. Reference has already been made to the use of varying terminology in different countries. Whilst every effort has been made to make the reports consistent, the different terms for clayware and other materials have been retained in certain countries where it is thought these indicate the specification in use.

61. Whilst metrication is almost universal, there is considerable variation in the adoption of the centimetre or the millimetre as the basic unit and also in the use

of decimal points. Comparison is preferable in metric units but cannot be precise since conversion from imperial to metric units must involve some loss of accuracy. If inaccuracies have crept in as a result of the difficulties of translation, we apologise to those good enough to furnish us with the information upon which we have based the brief reports contained in the appendix. A summary of these reports now follows.

Summary of reports on overseas practice

Responsibility for sewerage

62. In most countries sewerage in towns is the responsibility of the town council. Outside towns the position varies. In Zambia the government's Works Department are responsible for works in rural areas, while in France the Rural Management Section of the Ministry of Agriculture issue instructions for the construction of sewers in rural areas. In some countries district councils are responsible for sewerage.

63. Where standards and codes of practice exist there is usually reasonable uniformity within a country, but where towns are autonomous and widely separated considerable variations may occur within a country. This wide variation within a country is confirmed by the results of the questionnaire from fifty sewerage authorities in New Zealand.

Use of standards

64. Many English and German speaking countries have standards or codes of practice similar to those issued by the British Standards Institution. British Standards are used as a basis of construction in many parts of the world, particularly those in the Commonwealth. Many Central European standards are based on the German standards.

65. France has a series of standards similar to British Standards, which are frequently sub-divided so that each document covers only one type of pipe in a particular material.

66. Australia, Canada, New Zealand, Czechoslovakia, Denmark, Finland, Holland, Sweden, West Germany, Austria, India and Japan have standards for most pipes used in their own country. Many of these countries also have codes of practice or include information on design and construction in the standards.

67. The Argentine Ministry of Public Works have published specifications for the construction of sewers.

68. Some parts of Canada rely on American standards and New Zealand, Malaysia and Singapore follow some of the Australian standards. Some of the Indian standards match the standards of the countries from which the materials are imported.

69. Few countries have regulations requiring that sewers be constructed in accordance with standards or codes of practice. Whilst the standards or codes of practice are good guides of recommended practice in particular countries, it does not necessarily follow that sewer construction is usually in accordance with these documents.

Materials used for sewers

70. A wide range of materials is used for sewers including:

asbestos cement pipes;
bricks;
cast iron pipes;
clay pipes;
concrete;
concrete pipes, plain or reinforced;
pitch fibre pipes;
polyvinyl chloride (pvc) pipes; and
steel pipes.

Clay and concrete pipes are used more widely than any other material. It is claimed that clay pipes have an advantage over concrete pipes in respect of their resistance to attack from aggressive sewage. The cost of clay pipes rises with diameter more steeply than the cost of concrete pipes and the point at which concrete is preferred depends to a large extent on the relative costs of production in each country. The following diameters of clay and concrete pipes are listed in the respective standards or reported to be used in the respective countries:

Country	Clayware	Concrete
Austria	Up to 400 mm	Ovoid
Czechoslovakia	Up to 600 mm	100 to 1200 mm
Denmark	—	100 to 2500 mm
Finland	Up to 400 mm	100 to 1800 mm
France	Up to 600 mm	100 to 1800 mm
Holland	House and street drainage	300 to 1500 mm
Italy	Up to 400 mm	Ovoid
Sweden	100 to 600 mm (rarely used)	100 to 2000 mm
Switzerland	Up to 600 mm	250 mm upwards
West Germany	100 to 1200 mm	100 to 1400 mm
Israel	Up to 500 mm	100 to 1400 mm
Australia	100 to 600 mm	300 to 2000 mm
New Zealand	100 to 370 mm	Most sizes
Canada	100 to 300 mm	100 to 2700 mm
United States	100 to 1200 mm	300 mm upwards
Argentine	100 to 350 mm	65 to 1000 mm
Colombia	200 to 750 mm	400 mm upwards
Malaysia	150 to 370 mm	450 to 1800 mm
Hong Kong	Up to 600 mm	Over 600 mm
Japan	—	75 to 1800 mm
India	100 to 600 mm	80 to 1800 mm

In Austria, Czechoslovakia, West Germany and Israel advantage is taken of the attributes of both clay and concrete by using vitrified clay linings at the inverts of concrete sewers. Other acid resistant materials are used to increase the resistance of concrete sewers to acidic trade wastes in a number of countries. The use of a plastics or epoxy resin lining to resist attack is increasing. In West Germany sewers are also constructed of clayware sections surrounded with concrete, or lined with bricks. Large sewers in Austria have clinker brick inverts. In U.S.A. limestone and dolomite aggregates are used for concrete pipes in the south where they are likely to suffer attack by hydrogen sulphide. Plastics lined concrete pipes are used in Australia, Israel, U.S.A. and Singapore. The resistance of concrete to abrasion and chemical attack is increased in some countries by the use of additives or by painting with bitumen etc., but painting is said to be less effective.

71. Austria, France, Italy, Switzerland, West Germany and Israel are known to use ovoid sections. The City of Amsterdam has ceased to use oval sections but they are still favoured in Italy and used in France because of their hydraulic properties at low flows. In West Germany some of the larger ovoid sections are wider below the mid-height of the section than above.

72. Flat based pipes are used in Denmark, Sweden, Switzerland, West Germany and Finland, but their use has been discontinued in Holland. In West Germany they are considered to be easier to lay than round or oval pipes.

73. In northern Italy larger sewers are normally constructed of in-situ concrete pipes with a granolithic or brick lining. Some in-situ concrete sewers with brick linings are constructed in Colombia, and in-situ concrete sewers are constructed in Austria, Czechoslovakia, Hong Kong and Israel. Cast in-situ sewers are used for surface water sewerage in the U.S.A.

74. Trinidad requires concrete pipes to be constructed of sulphate resisting cement. Singapore requires concrete pipes to have a high alumina or pvc lining, or to be of sulphate resisting cement.

75. The use of steel plate pipes lined with concrete internally and externally seems to be confined to India. Pre-stressed pipes are used in Holland, India and Argentine but do not appear to be used in large quantities elsewhere.

76. Some large sewers in Spain are constructed of rendered brickwork with vertical walls.

77. Small diameter plastics pipes are used in most European countries, Israel and Hong Kong. The usual plastics pipe material is pvc.

78. Asbestos cement pipes are used in France, Holland, Switzerland, India, Israel and Singapore.

79. Small diameter pitch fibre pipes are used in poor ground in Holland and to a limited extent in Malaysia, Singapore and Ghana. Pitch fibre pipes have been introduced into Zambia following the restrictions on the import of asbestos from Rhodesia.

80. Y branches and T's have very short branches in some countries, notably Finland and Argentine.

81. The minimum diameter of sewers in France is 150 mm for foul sewers and 250 or 300 mm for surface water sewers. Italian and Austrian practice is similar although smaller surface water sewers are permitted. The minimum size of sewer in most parts of North America is about 200 mm.

82. A number of countries are investigating new materials including other types of plastics pipe and glass fibre reinforced pipes.

83. The types of joints generally used can be summarised:

Czechoslovakia	bitumen or mortar joints.
Denmark	mechanical joints.
Finland	mechanical joints, clay joints in clay strata or cement mortar joints if socket lined with bitumen.
France	mechanical joints or tarred rope and bitumen.
Holland	mechanical joints for concrete pipes and pvc house drains; round foam rings and flanged rings for clay pipes.
Sweden	mechanical joints.
West Germany	mechanical joints now being used in greater quantities to speed construction.
Israel	mechanical, cement mortar or bitumen joints.
Australia	mechanical joints although some cement mortar joints are used.
New Zealand	mechanical or cement mortar joints.
United States of America	mechanical joints.
Argentine	mastic asphalt or cement mortar.
Colombia	mechanical joints preferred.
Singapore	mechanical joints.
Zambia	mechanical joints preferred.
Ghana	cement mortar or bitumen joints.
Hong Kong	rigid joints but mechanical joints in reclaimed areas.
India	a bandage joint of mortar and hessian is permitted in addition to the usual rigid and mechanical joints.

Location of sewers

84. Sewers are generally laid under the edge or centre of highways, the relative position of services frequently being the subject of regulations. Some countries consider it is important to locate the foul sewer below the surface water sewer. Where the sewers are parallel the foul sewer is frequently laid under the side of the surface water sewer. Manholes may be constructed with dividing walls to give access to both sewers. In Colombia it is considered desirable for a foul sewer to be below a surface water sewer at crossings. In Czechoslovakia sewers are generally located below water mains and as a result are at least 3 m deep. Israel requires sewers to be 1 m from water mains in a horizontal direction and water mains to cross above the sewer or the sewer to be located in a sleeve pipe.

Extremes of heat and cold

85. In Saskatchewan, Canada, sewers are laid at a depth of at least 8 ft as frost may penetrate to this depth.

86. Sewers are also constructed in Austria to avoid frost penetration, which it is claimed can reach a depth of 3 to 4 m in cities. In Sweden sewers are likewise constructed to avoid frost, which it is said can penetrate fine sand 1·2 m in the south and 4 m in the north. In some soils the depth of laying can be reduced by taking account of the heat of the sewage.

87. In many countries the use of frozen material for backfilling is forbidden and in Japan it has been suggested that trenches should be filled with materials which are more frost resistant where the excavated material is unsuitable and frost damage is likely. Surface water inlets in Austria are constructed so that they increase in area in a downward direction and do not become blocked with snow.

88. Heat does not seem to cause many difficulties, although a number of countries are concerned about hydrogen sulphide attack on concrete sewers and spend considerable sums on lining sewers. This may be a factor in the greater use of clay pipes in warmer climates. Sulphate resisting cement is used more extensively in the warmer climates. Heat is also a possible reason for the cautious approach of some countries to the use of plastics pipes. Some countries are requiring discharges of sewage to be kept below a specified temperature, the sewage being diluted with cooler liquid, to reduce the risk of pipes being damaged.

Excavation of trenches

89. Many countries have regulations specifying the excavation of trenches and the methods to be used to support the sides to ensure the safety of the men working in the trenches. West Germany, for example, requires timbering if the trenches are over 1·25 m deep. Widths of trenches are laid down in Czechoslovakia for different depths. Holland uses a trench with a side slope of 4 vertical to 1 horizontal 250 mm wider than the pipe, while Austria limits the taper to the lower portion of the trench. Canada permits a V trench as an alternative to a narrow timbered trench.

90. Sweden, Switzerland, Israel, Australia and New Zealand specify a minimum trench width and Canada a maximum width. Zambia specifies the width at the crown of the pipe and Trinidad requires trenches to be as narrow as possible. The advantage of keeping the lower parts of trenches narrow is stressed in a number of countries. In Sydney attention is drawn to the need to reconsider the bedding if the specified trench width is exceeded, and to the advantages in open country of open cut excavation and trench type loading if excavation is with sloping sides down to 2 ft above the pipe and vertical sides below that level. In the United States of America battered trenches are frequently excavated by machine. In other countries the lower parts of a trench are often excavated by hand and backfilling carried out in layers from 150 to 300 mm thick.

91. West Germany, Italy and Czechoslovakia stress the need to drain trenches, and some schemes incorporate a permanent drain below formation. Some designers prefer to use a layer of sand as a drain because if a layer of gravel is used there is a possibility that soil may seep into the voids and weaken the lateral support of the sewer.

92. Switzerland does not permit machine excavation below the top of pipes and requires the cavity formed when trench supports are withdrawn to be filled with concrete.

Bedding of pipes and backfilling of trenches

93. The normal bedding for small sewers is:

Austria	100 mm of sand or lean concrete, or bed and haunch with 50 mm of concrete.
Czechoslovakia	the natural soil if soft for pipes up to 350 mm diameter, sand or concrete surround for 500 mm diameter pipes; and 150 to 200 mm concrete surround for larger pipes.
Finland	trench bottom, supported on wedges and rubble, gravel and sand bedding for pipes up to 400 mm diameter; or a concrete bed for larger pipes.
France	fine soil.
Holland	loose sand although gravel may be used in clay soil.
Ireland (Republic of)	granular bedding.
Italy (Milan)	concrete bed and haunch.
Sweden	trench bottom or 150 mm of gravel if trench bottom is unsuitable.
Switzerland	granular bedding, concrete bed, part concrete surround or complete concrete surround.
West Germany	a 60° to 90° bedding constructed in the trench bottom if suitable, sand, fine gravel or concrete, the last named being used if there is a chance of the bed spilling. In Munich, however, a surround of sand (grading up to 7 mm) is used for sewers up to 350 mm diameter, and larger sewers are bedded and haunched with concrete.
Israel	shaped trench bottom, levelled surface of sand, granular material, concrete saddle, bed and haunch or surround; sewers with less than 1 m of cover are protected with concrete and those more than 3 m deep are covered with a reinforced concrete surround or are constructed of special pipes.
Australia	granular bedding, concrete bed and haunch or concrete surround.
New Zealand	trimmed trench bottom, granular bedding, concrete bed and haunch or concrete surround.
Canada	concrete bed with granular fill above the pipe in Vancouver, 75 mm bed of sand up to pipe springing sometimes with a granular fill in Saskatoon.
United States	normally granular bedding but variations range from the natural trench bottom to encasing in 125 mm of concrete.
Argentine	trench bottom.

Colombia	block of concrete up to $\frac{1}{3}$ or $\frac{1}{2}$ height of pipe for small sewers, larger pipes on excavated material; concrete surround if pipes have less than 1 m cover.
Jamaica	loosened trench bottom if it consists of sand or 3 in bed of sand.
Trinidad	gravel bedding passing 37 mm screen or concrete bed and haunch.
Malaysia	concrete haunch or surround.
Singapore	granular fill, pipes being supported by blocks, or concrete bed and haunch or surround.
Zambia	75 mm layer of 18 mm gravel well watered and compacted.
Ghana	trench bottom, but concrete bed may be necessary in some locations.
Hong Kong	concrete bed and surround.
Japan	concrete foundations where necessary.
India	rounded trench bottom or concrete bed and haunch; pipes laid in embankment should be placed in trenches after embankment has been constructed.

Foul and surface water pipes are frequently laid in the same trench as each other in Austria. The lower pipe is surrounded with concrete and the concrete carried up to the centre line of the upper pipe. Normally the trench is taken down for the full width to the lower pipe and the upper pipe supported on a rectangular block of concrete but the excavation may be cut at 45° under the upper pipe to reduce the amount of concrete. Many countries lay pipes on a trimmed trench bottom, which is sometimes shaped to the curvature of the pipes. Those countries surrounding pipes with concrete usually break the surround at frequent intervals. Well graded $\frac{3}{4}$ to $\frac{3}{16}$ in crushed stone bedding or sand bedding is regarded as the most desirable bedding. The danger of the gravel bedding becoming a drain and itself becoming washed away is a possibility on sloping sites and the bed may have to be secured by the construction of concrete walls or replaced by concrete.

94. In Israel shallow pipes under roads are laid in sleeve pipes. In Los Angeles and parts of New Zealand sewers are protected by a concrete blanket if they are near or likely to be near another sewer.

95. Timber or concrete piles are used in a number of countries to support pipes or their bedding where the ground gives poor support. In Japan timber piling is placed so that it is below the water surface to prevent deterioration from alternate drying and soaking. In Holland timber piles with cross beams are used in peat and wooden frames in soft ground. Surface water drains are laid on planks. In Sweden planks or cast in-situ concrete slabs on timber, concrete or steel piles are used if the trench bottom is poor. In Finland pipes are supported on planks or poles and surrounded with sand in poor ground. In parts of Canada cast iron pipes or pipes supported on long planks are used in filled ground. In Australia pipes laid in filled ground may be supported on piles and bearers or on a concrete raft. In Dunedin, New Zealand, pipes laid below high tide level are laid on an

all-in graded base with paving slabs to support the sockets. One or two countries consider pitch fibre pipes have some advantages in soft ground and that the support conditions for these need not be so strictly controlled as those for other materials. The need to backfill with selected material around and over pipes is generally accepted, sand being the most favoured material. A number of countries consolidate backfilling, particularly sand, by flooding trenches followed in some areas by light tamping.

96. It does not appear that compaction is always given the serious attention it deserves. In Holland the need to avoid compacting directly over a plastics pipe is noted.

Basis of design

(a) Hydraulic

97. Sewers have been designed to produce the following velocities:

Austria	0·5 m/s.
Czechoslovakia	maximum of 10 m/s if constructed of clayware or brickwork and 5 m/s if of concrete, provided the inverts of the latter are lined if the velocity exceeds 3 m/s.
Ireland	maximum of 10 ft/s (3 m/s).
Switzerland	minimum of 0·6 (0·5 extreme) m/s; maximum of 8 m/s have been satisfactory.
New Zealand	½ full minimum of 2 ft/s (0·6 m/s) for foul sewers and 2½ ft/s (0·8 m/s) for surface water sewers.
U.S.A.	½ full minimum of 2 ft/s (0·6 m/s) and maximum of 12 ft/s (3·7 m/s).
Colombia	minimum of 0·4 (0·75 for full storm sewage pipe) m/s, maximum of 4 (3 for storm sewage) m/s. The maximum may be increased to 5 m/s if the pipe is surrounded with concrete.
Malaysia	maximum 8 ft/s (2·5 m/s).

The following have been used for calculations of flows:

Austria	foul sewage—250 litres per person per day: surface water—a once in 1½ or 2 years' storm.
U.S.A. (Los Angeles)	domestic sewage—85 U.S. gallons (322 litres) per head per day, industrial sewage 0·008 ft^3 (0·227 litres) per second per acre.
Colombia	120–290 pints (57–137 litres) per house per day depending on the district. 0·4 U.S. pints (0·189 litre) per hectare per second for undeveloped industrial areas; infiltration 0·1 U.S. pints (0·473 litres) per hectare per second.
Australia	4·3 persons per dwelling and 60 gallons (273 litres) per head per day.

(b) Structural

98. Designs in many countries are based on the theories of Marston and Spangler whilst in others traditional construction is adopted without a detailed assessment of the loading and conditions. In Japan it is recommended that the allowable load on the soil be determined by load bearing tests. The Iowa methods of calculating loads have been questioned by a number of sources, and alternative calculations for the load by the embankment theory have been put forward by Pruska of Czechoslovakia and Voellmy of Switzerland. Wetzorke of Germany and others have investigated the trench load theory. In spite of the criticisms, the Iowa methods of calculation appear to be the most widely used methods of design. Design tables prepared in New Zealand have been developed on the basis of safety factors of 1·5 to 2·0 against cracking, the pipes being classified into pipe strength groups. The French Ministry of Equipment recommends that pipes be designed using a factor of safety between 2 and 2·7 but that the factor be raised to 3·5 for non-standard bedding; the Ministry of Agriculture recommend a safety factor of 3. In Israel a safety factor of at least 1 is used on the minimum ultimate breaking load and between 1·2 and 1·5 based on the average value. Permitted loadings on clay pipelines are reduced to $\frac{1}{3}$ in Australia if there is any chance of the socket resting on the sub-grade.

Manholes

99. Nearly all countries construct manholes at junctions, changes of section, direction and gradient and at the ends of sewers.

100. In India it is not considered essential to provide a manhole at every change of direction on curves up to 30° and preferable to locate manholes at tangent points as they are easier to construct on straight lines than on curves. Many manholes are omitted on sewers in which men can stand. It is considered that the spacing of manholes is dictated by

(a) the distance of hauling silt;

(b) the distance of carrying materials for repair; and

(c) ventilation.

101. Recommended spacings for manholes vary from 30 m on small sewers in Italy to 150 and 200 m in some countries on larger sewers which can be entered. A spacing of 100 m is an average figure in all conditions.

102. Although precast concrete rings are the most widely used form of manhole construction, in-situ concrete and brick and masonry manholes are still used in many countries. Use is divided between rectangular and circular shapes, oval manholes being used to some extent in Switzerland. Walls may taper or rise vertically to the access cover. There is a tendency notably in Sweden to use manholes with the bottom part including inlets and outlets prefabricated.

103. In Austria many manholes are divided to provide access to both the foul and surface water sewers.

104. In Finland circular ring manholes have taper rings some of which taper unsymmetrically on all faces while others have one vertical face. In Czechoslavakia the lower portions of manholes are constructed of in-situ concrete and the remainder of the chamber of precast concrete rings, the uppermost tapering unsymmetrically.

105. Many Dutch domestic manholes have masonry walls while surface water manholes consist of pre-cast concrete rings to which clinker blocks are mortared.

106. In Switzerland, perforated ventilating covers may be provided to manholes every 200 m.

107. Manholes in Tel Aviv (Israel) are normally 1 m diameter of in-situ reinforced concrete, but those on pipes larger than 1 m diameter are square or pentagonal of brickwork and reinforced concrete.

108. In Los Angeles and Australia manholes with plastics lining are used in certain locations.

109. Manholes vary in size from country to country and, depending on the size of sewer, within a particular area. They range from 400 × 600 mm to 2000 mm diameter with 900 to 1000 mm diameter being the most common size.

110. The need for flexibility between manholes and sewers is noted in a number of countries and this is usually achieved by building sockets into walls and providing short pipe lengths with flexible joints outside the chambers.

Curvature of sewers between manholes

111. The use of curved sewers has increased in U.S.A. because of a trend towards curved streets, and because improved sewer maintenance equipment has lessened the need for straight alignments. The curve is usually made by angling a pipe joint up to 3°. Curved sewers are seldom laid with radii less than 100 ft and many cities consider 200 ft to be the normal minimum. Large diameter curves are permitted in New Zealand provided a man can be seen from a manhole and the manholes are not more than 300 ft apart. Curves are also permitted in Czechoslovakia, Israel, Australia, India and Singapore.

Flushing tanks

112. Flushing tanks, designed to flush once a day, are used in India if the flow is never sufficient to fill half the pipe and maintain a self cleansing velocity. They are also used in Austria and Israel, but are going out of favour in France. In Israel they are designed on the basis of a discharge of 2 litres per person per day.

Research and development

113. In both Russia and West Germany there has been a trend towards locating service pipes in large ducts. The location of sewers in these ducts is not as easy as it is for other services as the required fall is not always available.

114. In Czechoslovakia, bridges, blocks and cushions have been used over pipes for relieving the load. Inflatable plastics cores are used for the construction of in-situ circular and non-circular sections and their use has been extended to the concreting of chambers.

115. In West Germany thixotropic* fluids are used to keep trenches open where the sub-soil water is high. Freezing is now used for trenches as well as shafts. Clay pipes are being manufactured in lengths of 1·5 m to reduce the number of

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*A thixotropic fluid is one which behaves like a liquid when agitated and like a solid when at rest.

joints. Pipes and junctions are being developed with thicker walls to obviate the need for concrete surround. Plain concrete pipes are being manufactured in longer lengths of 1·5 and 2 m instead of 1 m. The assembly of a series of plastics pipes prior to lowering them into a trench is thought to be an advantage.

116. In view of the criticisms of the Marston theory and the suggested alternatives, Janson of Sweden investigated the loads on rigid underground pipes using load boxes and experimental lengths of pipe giving particular attention to the embankment theory. Other workers in Sweden have examined in a similar manner the problems of loading on flexible pipes, and tests are being carried out in Finland and Sweden to fix the limits of stress and strain for plastics pipes. Attention is now being directed to drafting laying instructions for flexible pipes.

117. In France load tests have been carried out on a 'carousel', an apparatus in which a loaded wheel rolls around a circular track applying a load at regular intervals to a buried pipe. Traffic load tests associated with this work are being carried out in Finland. It is hoped, as a result, to study the long-term deformation of plastics pipes of varying rigidity. The effects of temperatures on plastics pipes have been studied in Finland, Sweden and West Germany.

118. Professor Horler of Zurich considers that the hydraulic gradient should dictate the construction of junctions between larger and smaller sewers. Tests have been carried out in Switzerland to determine the minimum cover of pipes necessary to protect them from damage by the use of various methods of compaction.

119. The Japanese have carried out an experimental study of loads on pipes and in Argentine the effects of different methods of prestressing have been examined to ensure that the mortar protecting the steel does not become overstressed.

120. The problem of hydrogen sulphide and sulphuric acid attack on concrete pipes has been considered by research workers in South Africa and Australia. In the meantime plastics and other linings to both sewers and manholes are being used to an increasing extent. A wide variety of resins, paints and sprays are being used to protect pipes.

121. In Australia experiments have been conducted to measure the beam loads and joint shear loads to which mechanically jointed pipes are subjected. When the results were applied to design it was found that the tolerances required were so stringent that the cost of pipe manufacture rose considerably, and it was accordingly decided to relax the tolerances and risk an occasional defective joint. Tests for root penetration of rubber rings have been carried out. Fibreglass overflows, vortex drops, plastics linings and stainless steel shafts are being tested.

122. A number of tests are being carried out in certain countries on materials which have not been on the market for long. These include high density polythene and glass fibre reinforced polyester pipes.

123. Limited research has been carried out in U.S.A. to check the accuracy of the Marston theory for the calculation of the structural loads on pipelines.

124. Other research is being carried out in New Zealand to determine realistic design criteria relating to quantities of sewage and infiltration for different types of building in different areas.

Comparison with British practice

125. From the summary and the individual short reports it is difficult to pick out how far practice in other countries differs from our own. It was accordingly decided to draw up the following chart indicating in general terms how practice in each country compares with British practice and the main differences. The chart draws attention to the variations and similarities, most of which have been noted in earlier paragraphs of this report or in the appendix. Whilst we do not wish to appear complacent, it is gratifying to conclude that British practice is in most respects similar to if not better than the best overseas practice. New materials are continually being introduced and it is in our own interests to maintain contact with those responsible for the considerable research and development which is being undertaken in overseas countries. In this way we shall avoid unnecessary duplication of research, be able to keep up with progress and expedite and make more efficient our own research.

Chart summarising overseas practice

Notes

126. The following symbols have been used in the chart where details are available:

'A' under a particular column against a country indicates that the use of that material or type of construction is similar to British practice.

'X' under a particular column indicates that the material or construction is used in that country but that the information does not fall into one of the categories listed below or is limited.

1. LARGE SEWERS

A. *Concrete pipes*

E	Ovoid pipes.
Fb	Flat based pipes.
Op	Circular pipes with polymer joints.
Pa	Pipes cast in-situ and sometimes lined with acid resistant material.
Pc	Pipes lined with clay sections or clinker brickwork.
Pl	Pipes lined with high alumina cement or pvc.
bj	Bitumen joints.
mj	Cement mortar joints.

B. *Clay pipes*

bj	Bitumen joints.
mj	Cement mortar joints.

C. *Asbestos cement pipes*

Pl	Pipes lined and coated.

D. *Other materials*

B	Brickwork.
BC	Brick/concrete in-situ construction.
CI	Cast iron pipes.
S	Steel pipes.
PVC	Polyvinylchloride.

2. SMALL SEWERS

E. *Concrete pipes*

As	Similar to British practice but using sulphate resisting cement.
Pl	Pipes lined with high alumina cement or pvc.
bj	Bitumen joints.
cj	Clay joints.
mj	Cement mortar joints.

F. *Clay pipes*

E	Ovoid pipes.
bj	Bitumen joints.
mj	Cement mortar joints.

G. *Pitch fibre pipes*

H. *Plastic pipes*

I. *Iron and steel pipes*

CI	Cast iron pipes.
S	Steel pipes.

J. *Asbestos cement pipes*

3. BEDDING

K. *Granular bedding*

s	Sand.
sc	Sand, but gravel used in clay.
sg	Sand and gravel mixture.
s/g	Sand or gravel.
wg	Wood blocks followed by gravel bedding.

L. *Concrete*

S	Concrete surround.
lc	Lean concrete.

M. *Other*

ø	Pipes constructed in common precast duct.
br	Experimental use of bridge, blocks and cushions to relieve stress.
cp	Pipes supported on concrete piles.
pk	Pipes supported on planks.
ps	Pipes on concrete slabs in poor ground.
sl	Pipes laid on soil or trench bottom.
tb	Pipes supported by timber beams on piles in marshy ground.
tp	Pipes supported on timber piling.

4. MANHOLES

N. *Precast concrete*

O	Circular.
R	Rectangular.
T	Thick walled rings.

O. *In-situ concrete*

O	Circular.
OV	Oval.
Pl	With plastics lining (and clay pipe shafts in U.S.A.).
R	Rectangular.

P. *Others*

B	Brick.
M	Masonry.

R. *Location*

S. *Notes on spacing*

(a) 35 m for sewers which cannot be entered and 80 m for sewers which can be entered.

(b) 50 m apart for sewers up to 1500 mm diameter and 100 m apart for larger sewers.

(c) 20 m apart in Amsterdam.

(d) 30 m apart for sewers which cannot be entered and 50 m apart for sewers which can be entered.

(e) 50 to 65 m apart for 500 mm pipes, 50 m apart for 600 to 900 mm pipes and 80 to 100 m apart for 1000 to 1250 mm pipes.

(f) 35 to 50 m apart for pipes up to 500 mm diameter, 100 to 150 m apart for pipes which can be entered.

(g) Considerable variations exist within Australia; one authority locates manholes 130 m apart while another allows them to be spaced up to 300 m apart for sewers over 48 in diameter.

(h) Considerable variations within this range in different localities but a spacing of 100 to 130 m is commonly used.

(j) 90 m for sewers over 500 mm and up to 900 mm diameter, 75 m for sewers over 300 mm diameter and up to 500 mm diameter and 45 m for sewers up to 300 mm diameter.

(k) With modern high pressure jetting equipment it is thought that manhole spacing can be increased to 120 m.

(l) Up to 50 m for pipes up to 600 mm diameter, 50 to 80 m apart for pipes 600 to 800 mm diameter and 80 to 100 m apart for pipes over 800 mm diameter.

(m) 60 m for pipes 200 and 300 mm diameter and 80 m for larger pipes.

Comparison of Overseas construction with British practice

Country	1. Large Sewers (300 mm dia and over)				2. Small Sewers			
	A Concrete	B Clay	C Asbestos Cement	D Other Materials	E Concrete	F Clay	G Pitch Fibre	H Plastic
Europe								
Austria	A.Pa.E					X		X
Czechoslovakia	Pa.mj.E	bj	X	B.CI.S	mj	bj		X
Denmark	A.Fb				A			X
Finland	A.Fb	X			A.cj.bj	X		
France	A.E	X.bj	X	S	A	A.bj		X
Holland	A		X	CI.PVC	A	X	A	X
Ireland (Republic)	A				A	A		X
Italy	Pa E	X			X	X.E		
Russia	Op							
Spain	X	X		BC	X	X		X
Sweden	A.Fb	X			A	A		X
Switzerland	A.E.Fb	X	X		A	A	X	X
West Germany	A.Fb.E.Pc	X	A	BC	A	A		X
Middle East								
Israel	mj.bj E.Pa.Pl	X	A	CI.S	mj.bj	A		X
Australasia								
Australia	A.Pl	X				A		
New Zealand	A	X	X			A		
North America								
Canada	X		X		X	A	A	
United States	A.Pl	X	A.Pl	S		A.bj.mj	X	
South America								
Argentine	X.mj.bj	X.bj	X		mj.bj	bj		
Brazil					X	X		
Colombia	A.Pa	X		BC		X		
West Indies								
Jamaica					A			
Trinidad					As			
Fed. of Malaysia								
Malaysia	A	X		CI	A	A	A	
Singapore	Pl.As		A	S.CI	Pl.As	A.mj	A	
Central Africa								
Zambia					A	A.mj	A	
West Africa								
Ghana					bj.mj	bj.mj	X	
Japan and Hong Kong								
Hong Kong	mj	mj				A.mj		X
Japan	X				X			
India	A.mj		X	CI	A.mj	X		

3. Bedding					4. Manholes				
I Iron & Steel	J Asbestos Cement	K Granular	L Concrete	M Other	N Precast Concrete	O In-situ Concrete	P Others	R Location	S Spacing (Metres)
		s	S.lc	sl	O.R.	O.R.			35–80 (a)
CI.S	X	s	A	sl.br.ps	X	X		A	50–100 (b)
		sg	X	sl.pk.ps	A	X		A	50–70
S	X			sl	X	X	B.M	A	50–80
CI	X	sc		pk.tb	O.R.		B.M	A	50–70 (c)
	X	A	A		A			A	
			A			R		A	30–50 (d)
				ø	X				
				sl.pk.ps	A	X			70–100 (k)
CI.S	X	A.s	A			O.OV		A	50–100 (e)
CI.S	A	s/g	A	sl	A			A	50–100 (1)
CI.S	A	s/g	A	sl.tp	O.R.	O.R.	B	A	35–150 (f)
CI	X	A.s	A	sl.tb	A.C.	X.Pl	B	A	100–200 (g)
	A	A.s	A	sl.ps	O.R.	X		A	100 (aver)
CI	X	A.s	A	pk	A	X	B	A	100–160
S	A	A.s	A	sl.	A.T.	X.Pl	B	A	100–500 (h)
CI.S	X		A	sl					
			X	sl	A	O	B.M		
	A	s	A	sl				A	100
		A	A	sl	A	X	B.M		
CI	A		A		A		B	A	A
CI.S	A	wg	A	sl.tp.cp	A	X			
CI	A	A	A		A		B		
CI.S	A		A		A				
CI			X.S	sl.cp					
			X	tp.cp					
CI	X	A	A	sl		O	B	A	45–90 (j)

Section C. Research

Research into pipe design

127. In paragraph 243 of our second report we recommended that a new research section be set up at one of the Government research establishments to carry out a major programme of experimental work in connection with the design and construction of underground pipe sewers. The formation of such a research group and the expenditure of £500,000 were authorised early in 1969. The former Ministry of Transport agreed that the group should form part of the Road Research Laboratory at Crowthorne, Berkshire. The team will benefit from the considerable technical and administrative resources of that laboratory.

128. The research group was set up in April 1969 and a Panel consisting of representatives of the Working Party and the Road Research Laboratory was created to direct its activities.

Objects of research

129. The group's programme of work is being designed to investigate those matters which we, in our second report, considered to be most urgent, namely:

(a) determination of loads on sewers, including vehicle loads and impact effects;

(b) verification of the bedding factors in current use and examination of the properties of bedding materials which affect these factors;

(c) determination of the strengthening effect of concrete bed and haunch and concrete surround, and the considerations which affect their strengthening properties;

(d) research in connection with the design of lines of flexible pipes;

(e) investigation into the properties of pipe materials including particularly such matters as possible fatigue and creep effects; and

(f) investigation of the criteria used for the design of rigid pipe sewers in wide trench and embankment conditions.

Accommodation for the research group

130. The research group is at present working in temporary accommodation at the Road Research Laboratory but a special building is being constructed to house the group on the Road Research Laboratory site and should be ready by the end of 1971. This building will include a large pilot-scale laboratory, smaller laboratories to house testing machines and for instrumentation work and

offices for the staff. Additional facilities will include a sawing machine for cutting pipes into sections for mechanical tests, a hydraulic pump room to house the pumping equipment for fatigue-testing machines and storage space for large pipes awaiting test. The pilot-scale laboratory will incorporate a concrete-lined test pit in which pipes can be buried in various soils to simulate trench conditions. An overhead reaction frame above the pit will enable loads to be applied to the soil by jacks to simulate traffic and other loads.

Research programme

131. The research has been planned on the basis of a programme of field-scale experiments in which instrumented pipes will be installed in trenches under roads and submitted to traffic loading. This programme will synchronise with a programme of laboratory experiments.

1. *Field tests.*

It is proposed to install pipes under roads at 5 or 6 sites. The pipes will be instrumented so that strains and deformations can be recorded. Soil pressure cells will be inserted so that loads in the trench, at the trench walls and base and round the pipe can be measured. Since there are 24 different sizes of pipe in current use, in the range from 100 mm to 1800 mm diameter, it has been decided to use 3 sizes for the tests, 300 mm, 600 mm, and 1200 mm, and to use 3 depths of cover, 1·15 m, 2·3 m, and 4·6 m. Some 150 mm pipes will also be used. It is hoped to find sites, preferably within 50 miles of Crowthorne, with a range of different soil conditions. The objects of these tests will be to study the loadings on the pipes due to backfill, to traffic and to a combination of both. Normal road traffic and Road Research Laboratory vehicles of known axle loads will be used, the actual loads being counted and weighed by an electronic weighbridge. Measurements will be taken to determine how loadings due to the consolidation of the trench backfill by the traffic vary with time over a period of 2 to 3 years. The strains and deformations generated in the pipe will be compared with those causing failure in the normal British Standard tests and in special fatigue-type tests using combinations of static and repetitive loading. Since some pipe materials are subject to creep under load and are affected by moisture changes and age, the desirability will be considered of including some steel pipes on the field sites. The wall thicknesses of these will be chosen to give rigidities comparable to those of the equivalent pipe of plastics or other material and since they will not exhibit the creep properties associated with these materials analysis of the data will thereby be simplified.

2. *Laboratory tests*

(a) With pipes installed in soil boxes or in the test pit

Since the test pit will not be available until late 1971, a 1·8 m × 0·9 m × 1·8 m high test box in which pipes can be buried in soil and subjected to loads by hydraulic jacks has been constructed.

The objects of these tests are:

- i. preliminary tests of the instrumentation to be used in the field programme (soil pressure cells, strain gauges, etc.);
- ii. study of the performance of flexible pipes under load and examination of the way the results obtained fit the various theories, and study of the 'modulus

of passive resistance' of various bedding materials under different degrees of compaction, etc.;

iii. comparison of the behaviour under load of pipes of various materials and of steel pipes of equivalent rigidity; and

iv. study of bedding factors and of properties of bedding materials.

When the test pit becomes available it will be possible to apply repetitions of load at the surface and to carry out these tests with larger pipes than is practicable in the soil box. It will also be possible to study loading of pipes under wide trench conditions.

(b) Fatigue testing

When the building is ready it will contain facilities for the installation of fatigue-testing machines for investigating the effects of repetitions of load on sections of pipes of various materials and also combinations of repetitive and steady loads. The field-testing programme, and to a lesser extent the laboratory tests, will provide data on the loadings on pipes subjected to road traffic. It is hoped to be able to subject the pipe specimens to simulated combinations of static backfill loading and dynamic loading due to traffic and thus determine the effect of these factors on the life of the pipes.

3. *Advance trials in laboratory grounds*

Investigations of a 300 mm diameter steel pipe in a 0·9 m wide box have shown that the boundary conditions have a significant effect on the stresses in the backfill and in the pipe. The box tests are therefore regarded as a preliminary stage and it is intended to move to semi-full scale trials at an early date. Advance trials are to be carried out in the laboratory grounds. The top 2 to 3 m of soil will be removed over a length of about 20 m and replaced by compacted fill of heavy clay over half of the length and by well graded sandy gravel over the other half. This will provide sites for the installation and testing of various pipes. These tests will not be allowed to divert us from our aim to have field trials under road traffic conditions.

132. Due to the urgent need to determine loads on plastics sewer pipes and the best way to lay such pipes to resist these loads, priority has been given to investigating the design and construction of flexible sewer pipes. The remaining items in the programme will be investigated as soon as staff and facilities are available.

Present position

133. During 1969 and 1970, with both staff and accommodation limited, work has been proceeding on a number of instrumentation problems associated with the test programme, as well as the preparation of specifications for larger items of equipment which will be required later.

1. *Instrumentation*

Development work has been carried out on the following.

i. A small vibrating-wire strain gauge unit suitable for attachment to the interior wall of a pipe for the measurement of long-term strains. This gauge is a modified form of the unit developed by the Bridges Section of Road

Research Laboratory. Long-term tests carried out with these gauges attached to a steel bar suggest that their stability is adequate for use on large diameter rigid pipes. Further investigations are being made into the use of these gauges on small diameter pipes.

ii. A soil pressure cell intended for the measurement of both dynamic and long-term soil stresses. This device incorporates a small linear variable differential transformer, now available commercially, to measure the deflection of the cell diaphragm. Its main advantages are that it gives a larger signal output for a given diaphragm deflection than existing cells in which strain gauges are cemented to the diaphragm. It can be used for static as well as dynamic pressure measurements and has good long term stability.

iii. A displacement sensor for recording the internal profile of pipes. This device incorporates a displacement transducer mounted on a rotating arm which senses the deformation of the pipe wall at all points around the circumference. The displacement signal and the angular position of the sensor give the deformation in polar co-ordinates. Using a sine-cosine potentiometer these are converted to Cartesian co-ordinates and the pipe profile recorded by an X-Y recorder. It is intended to use this system, possibly with modifications, in laboratory loading tests on flexible pipes to record the deformations under load.

iv. The adaptation of an existing soil strain gauge developed by the Road Research Laboratory is under consideration.

2. *Preparation of specifications for equipment*

Major items of equipment for which specifications have been prepared include:

i. two pipe testing machines for carrying out the standard loading test laid down in BS 556:1966. The larger of these is capable of taking pipes up to 1800 mm internal diameter and applying loads up to 1000 kN. The smaller takes pipes up to 1200 mm internal diameter and can apply loads up to 250 kN.

ii. A data-logging system with 100-channel capability for use with resistance strain gauges and similar devices. This system is capable of resolving inputs down to 1 microvolt, the outputs being produced both as punched tape and as a print-out. High sensitivity is necessary in order to record small strains from resistance strain gauges when concrete or clay pipes are being tested.

iii. A test box for loading tests on pipes buried in soil. The test box at the Road Research Laboratory has been constructed using standard panel modules produced commercially for concrete shuttering. The box, 1·8 m high, 1·8 m long and 0·9 m wide, is mounted on load cells to record the weight of soil contained in it and is provided with an overhead reaction frame so that loads can be applied to the soil by means of hydraulic jacks.

Immediate programme

1. *Laboratory tests*

134. Experiments are being carried out in the soil box to determine how variations in the stiffness of the box walls affect the stresses and deformations in the pipes and soil. A 300 mm diameter thin walled steel pipe fully instrumented with resistance strain gauges has been installed in the box in dry, carefully graded

sand. Stresses in the sand and the pressure exerted on the pipe and the box walls are being measured by the pressure cells referred to earlier. The deformation of the pipe as it is loaded is also being recorded. The tests will then be repeated using a length of a pvc pipe of the same diameter and corresponding rigidity and with other types of soil. The objects of the test programme are:

(a) assessment of the performance of the test rig and of the instrumentation.
(b) comparison of the behaviour of steel and pvc pipes of comparable rigidity;
(c) examination of the theories for the deformation of buried flexible pipes under load;
(d) study of the relation of loads applied on the soil to the loads on the pipe and verification of the Marston theory of pipe loading and
(e) investigation of the 'modulus of passive resistance' of the soil used in the Spangler theory.

2. *Field experiment on a* 1800 *mm diameter steel pipeline*

An opportunity has arisen to carry out a limited programme of loading tests on the Kennet–Kirtling Green pipeline which is being constructed near Newmarket, Cambridgeshire as part of the Ely-Ouse Essex Water Scheme for the Essex River Authority.

The pipeline is being constructed of steel pipe, 1800 mm diameter and 12·5 mm wall thickness, laid on a granular bedding. Concrete encasing has been used where the pipeline passes under roads. Permission has been obtained from the Highway Authority to replace the concrete by a granular bedding where it passes under the roadway near Kirtling Village. This will make it possible to study the deformation of the pipe under traffic loads on the roadway using controlled vehicles of known axle load. The data from these field tests will provide an assessment of the validity of the Spangler theory when applied to buried pipes of large diameter and will complement the laboratory-scale tests on small-diameter pipes. This experiment is regarded as a preliminary exercise to the main programme of field tests, the first of which it is hoped to launch in the second half of 1971. Photographs of the pipeline and testing equipment face page 36.

Structural failures

135. In addition to laboratory tests and field experiments we have obtained valuable information from reports and inspections of structural failures of sewers. Information on the occurrence of failures has been difficult to establish and that on recent failures particularly hard to obtain as facts cannot be disclosed until contractual disputes are resolved. The failures mentioned below stress the need for constant care in design, manufacture and laying of pipes and the importance of good supervision. New construction nearby can easily damage an old sewer. The costs of investigating the trouble and replacing defective pipes are considerable; often far in excess of the cost of the original sewer. It is extremely difficult to maintain flow of sewage during repair work which frequently involves pumping through temporary pipelines. Failures as a rule are only brought to notice when there is a blockage or subsidence or a survey has been undertaken. We believe that there are a large number of minor failures in existing sewers which are not known until a fault appears on the ground surface or is suspected. The following failures have been brought to our notice.

136. In 1963 the ground over an old 12 in diameter sewer, constructed at a depth of 8 to 10 ft under meadowland without any concrete protection, was raised by nearly 10 ft when a car park was built over the sewer. Subsequently the sewer blocked and excavation revealed that the sewer had cracked along the soffit and at the sides. A considerable length was relaid. This failure is a warning of the possible consequences of building over an old sewer and imposing loads in excess of those for which it was designed.

137. A developer decided to culvert a stream by using 60 in diameter unreinforced concrete pipes under 10 ft of cover. The pipes were laid on rubble blinded with concrete. As would be expected from theoretical considerations the pipe failed.

138. A 30 in diameter concrete pipe sewer was constructed in about 1930 in heading at a depth of 18 to 20 ft under a main road. The sides of the heading were lined with precast reinforced concrete panels and the roof with close boarded timber. The sewer was surrounded with 6 in of poor quality concrete. A television survey revealed a number of cracks in the sewer. Excavation showed that the sewer had cracked at the soffit and the sides and had tended to become oval with the soffit rising and the sides yielding inwards. The concrete between the sewer and the roof of the heading had been poorly placed and there were many voids. It appeared that the timber roof had relieved the load on the top of the pipe where the concrete had been poorly placed and the load on the side walls had forced them inwards and the soffit upwards. The concrete pipes had been manufactured using high alumina cement and chemical conversion of the high alumina cement may have taken place resulting in loss of strength.

139. The joints on a 57 in diameter glass fibre wrapped concrete sewer laid to a slight curve permitted groundwater to enter the sewer. This example stresses the need to ensure that the actual curvature does not exceed the small amount recommended by the manufacturers. It is also essential to handle the joints of these pipes with care to prevent the glass fibre wrapping being damaged and to ensure that the rubber ring is correctly placed.

140. An 18 in diameter glass fibre wrapped concrete sewer was air tested satisfactorily on completion of construction but leaked about four to five months later. The leaks were found to be at the top part of the joints. The following reasons for the failures were suggested:

(a) faulty workmanship such as the rubber ring sliding into position instead of rolling;

(b) the washing of fines from the trench sides into the granular bedding resulting in excessive relative settlement of adjoining pipes; and

(c) faults in the pipes or rubber joint rings.

141. Fifteen-inch diameter sewer pipes 12 ft long under 4 ft to 8 ft 6 in of cover have cracked circumferentially.

142. Six-inch and 9 in diameter clayware pipes moved after backfilling and failed due, it is believed, to poor placing, compaction and grading of the bedding.

143. A 36 in diameter unreinforced concrete pipe sewer settled and failed due to inadequate bedding and the construction of a gas main near the trench wall.

144. A 24 in diameter surface water sewer 6 ft 6 in deep under a rural footpath collapsed. When the construction was examined it was found that the concrete

bed and haunch had been omitted and that a brick or bricks had been placed under each joint. A photograph of the damage faces page 37.

145. We have been informed of other failures including the failure within a few days of construction of 27 in diameter class I concrete pipes laid on concrete bed and haunch. The pipes were laid at a depth of 15 ft. Although the failure may result from a number of possible causes this particular instance serves as a reminder that the loadings permitted under form K29 construction can exceed those which rational design would allow.

146. We are grateful to the engineers who have supplied us with information on failures, but we need further information on any structural defects of sewers laid in the last 20 years. It is only from evidence of this nature and by relating it to our research that we can evaluate the real merits and limitations of the methods of design and construction which have been widely used during this period.

Temperature in sewers

147. The life of plastics pipe sewers and drains and the stresses which they are able to withstand depend on temperature and the latter usually depends on the temperature of the sewage. Although section 27(1)(b) of the Public Health Act 1936 limits the temperature of discharges to sewers to 110°F (43·3°C), temperature measurements are rarely taken and we are far from certain that the statutory limits are not exceeded. Enquiries from 16 large sewerage authorities indicated that most industrial discharges to public sewers are within the statutory limit although discharges from boilers, both domestic and industrial, and from wool scouring are likely to be high.

148. High temperatures can arise from domestic discharges such as those from washing machines and the draining down of hot water systems in an emergency. It can be argued that the latter is a rare event, but there is little point in constructing a drain which may have to be relaid whenever the hot water system is drained. Information on the temperature of discharges from domestic premises is extremely limited, and we consider it essential to obtain recordings of temperatures occurring in domestic drainage systems before we can advise on the structural design of plastics pipe sewers and drains. A check on the maximum temperatures of industrial discharges is also desirable.

149. The problem is a complex one in that the effect of continuous discharges is likely to be different from that of intermittent discharges. The thermal conductivity of the pipe, the surrounding material, the ambient temperature, the volume of flow of the discharge and the flow in the sewer are all likely to affect the rate at which the temperature falls along a sewer.

150. We propose to examine a number of drainage systems of different types. Recording thermometers will be installed at those points where high maximum temperatures are likely to occur to determine the actual temperature pattern. This important work will depend on the assistance and co-operation of a large number of local authorities and their engineers and we take this opportunity to record our thanks for the many offers of help we have received.

Liaison with pipe manufacturing associations

151. The associations representing manufacturers of sewer pipes were informed of the research programme and invited to comment on the proposals. We wish

to express our appreciation of the many constructive suggestions offered. In addition we value the information which some of the associations have provided regarding their own research work. We believe that co-operation in this way will enable results to be produced more rapidly to the benefit of the many interests associated with sewer construction.

Research being carried out by other organisations

152. From the investigation of overseas practice, referred to earlier in this report, the research team have obtained considerable information on research being carried out abroad into the structural design of underground pipe sewers. We have tried to contact all those carrying out research in this country in the belief that it would be a waste of resources for more than one laboratory to carry out similar work without exchanging information. Should there be any research of which we are still unaware, we would be grateful if the sponsors were to contact us with the object of an exchange of information on methods, instrumentation etc., to the benefit of both parties.

Rubber joint ring tests

153. In our first report we referred to reports from abroad of degradation of rubber joint rings and in our second interim report to the long-term trials of rubber rings which we proposed to carry out at Bracknell, Coventry and Ipswich. These trials have been put in hand. At each location 10 sets of rubber rings were mounted on formers so that they were partly immersed in a covered tank through which sewage flowed. A further 10 sets of rings were used to joint sewers, laid underground in field conditions through which sewage flowed continuously. Additional sets of rings have been sent to the Rubber and Plastics Research Association's laboratory and to the Natural Rubber Producers' Research Association's laboratory, as control sets. Each set of rings consists of one 9 in diameter ring and four 6 in diameter rings. The 9 in diameter natural rubber rings have been used to joint concrete pipes or have been placed on concrete formers while the 6 in diameter rings have been used to joint clay pipes or placed on clay formers. Each set of four 6 in diameter rings consist of one natural rubber ring, one natural rubber ring with styrene butadiene rubber additive, one butyl ring and one neoprene ring.

154. Sewage commenced flowing through the test plant at Chantry sewage treatment works, Ipswich, in September 1968; at Finham treatment works, Coventry, in July 1969; and at Binfield pumping station, Bracknell, in July 1970. Regular analyses of the sewage at each location are being made. The sewage at Ipswich and Coventry is principally domestic in character whilst that at Bracknell is mixed, some trade waste being present.

155. Considerable quantities of grease and other floating matter collected around the rings on formers. As joint rings in sewers are normally in contact with some floating matter it was decided that it would be appropriate to allow some grease to accumulate and to remove excessive floating matter periodically. A set of rings was withdrawn from the sewer and another set from the formers at Ipswich in October 1969. It was noted that the 9 in diameter ring which had been on a former partly submerged in sewage had a few fine hair cracks above the sewage line. Subsequently it was observed that the 6 in diameter rubber

ring and the 6 in diameter rubber plus styrene butadiene rubber ring on formers had similar cracks above the surface. It should be noted that the rings placed on formers are not under normal conditions and are only included in the tests as indicators. Other sets of rings were withdrawn from Coventry in July 1970 and Ipswich in September 1970 and sent to the laboratories for examination.

156. It is proposed to keep records of the permanent set in tension and the compression set of each ring that is withdrawn. At this early stage in the tests it is not possible to indicate whether the small amount of cracking on the first set of rings withdrawn from the Ipswich test plant has been due to ozone from the atmosphere, or whether the cracking is due to microbiological or similar attack. There was no indication of cracking on any of the rings withdrawn from the sewer at Ipswich in October 1969. Further sets of rings will be withdrawn at intervals to be determined by the condition of the rings that are examined.

157. We take this opportunity to express our especial thanks to the Clay Pipe Development Association Ltd., the Concrete Pipe Association and the three authorities who are undertaking the tests and to the Rubber and Plastics Research Association and the Natural Rubber Producers' Research Association who are examining the rings.

158. It is relevant to point out that these tests are being undertaken only because of the reports of deterioration of rubber joint rings from abroad. It is outside our terms of reference to test products generally; many new materials not covered by a British Standard are tested by the Agrément Board.

Section D. Summary and conclusions

Progress since our last report

159. Since the publication of the second report our efforts have been mainly concentrated on planning our research work at the Road Research Laboratory, Crowthorne. Recruitment of staff of the right calibre and the provision of equipment, instruments and a satisfactory building have in the outcome proved more complex and taken far longer than we had expected. With the commencement of construction of a laboratory designed to suit our requirements and the receipt of authority to build up the research team to its full complement, we feel we can look forward to a period of steadily increasing progress in our research. We have spent considerable time in planning the work and have sought the views of other interested parties so that the work should proceed expeditiously. Whilst we have made appreciable progress with instrumentation and other techniques, it is naturally too early for any results or recommendations to emanate from our research work. (Paragraph 133).

160. We have studied the need for and the use of manholes in considerable detail, as their cost forms an appreciable part of the cost of any sewerage scheme. Manholes are necessary for the inspection, repair and maintenance of sewers, to control rodents, to clear blockages and to enable connections and flow measurements to be made. We have directed attention to the maximum spacing of manholes on straight runs and have concluded that in the present circumstances the maximum spacing of 100 m or 120 yards on small diameter sewers is reasonable. In addition to this maximum spacing, manholes are currently located at all summits, changes of diameter, direction and gradient and at the junction of sewers. Indeed, many manholes meet more than one of these requirements and the frequency of use of a manhole for a particular purpose is likely to vary widely from manhole to manhole. (Paragraphs 7 to 12 and 26 to 32).

161. The replies to our questionnaire on manholes showed that detailed records on the use of manholes were not normally kept by sewerage authorities and that it was impracticable to compile statistics on the use and need for manholes at specific locations. We consider that, if sewerage authorities were to keep records of the use of manholes over a period, the information might result in a recommendation that the locations at which manholes are traditionally built should be amended. The construction of a small sewerage system in which selected manholes were omitted might indicate some locations at which manholes need not be constructed. (Paragraph 36).

162. The acceptance of curvature can affect the number of manholes which it is necessary to construct, in that curvature of sewers between manholes can enable physical obstructions to be negotiated without the need for a manhole at the intersection of two straight lengths. From the replies to our questionnaire on curvature we gained the impression that although many engineers had old sewerage systems with curves that were satisfactory, few of these engineers favoured the construction of new sewers with curves unless there was a clear financial advantage. As expected, the objections to curved sewers decreased as the size of sewer increased so that there were few objections to sewers being constructed with curvature if they could be entered by a man. We have therefore suggested that the minimum diameter of sewer to be constructed on a curve should be 36 in, but do not preclude consideration of curves on sewers down to 30 in diameter. Authoritative information, however, is lacking and the construction of a sewerage system with curves of varying radii might provide useful information on the extent to which curves could be used in sewerage design. (Paragraphs 18 to 20 and 34 to 36).

163. We regret to learn that many rigid pipe sewers and drains are still being constructed with rigid joints in spite of the opinion expressed in our second report that the use of mechanical joints should become virtually universal. We believe that so soon as sufficient production capacity of rigid pipes with mechanical joints is available to meet the demand for these purposes, rigid pipes with rigid joints should no longer be approved for loan sanction purposes. We see no reason why this should not be practicable within a relatively short time and certainly not more than two years beyond the date of 1972 implied in our second report. Since, however, this would not have any effect in controlling the large number of projects which do not require the Department's loan consent, consideration should subsequently be given to strengthening the clauses in Building Regulations which relate to the jointing of drainage pipelines. Wider publicity should be given to the advantages of mechanical joints by all appropriate means. (Paragraphs 38 to 42).

164. Our extensive investigation into overseas practice has enabled us to compare our methods of construction with those adopted overseas and to obtain valuable information on research being carried out in other countries. There are considerable variations in sewer design in different parts of the world, and understandable variations in construction techniques caused by the availability of labour and the relative costs of materials. We have noted the wide variations in the spacing of manholes and the use overseas of ovoid sections and flat-based pipes. We believe, however, that because circular pipes are easier to manufacture and as granular bedding becomes increasingly popular the use of non-circular sections will probably decrease. (Paragraphs 71, 72 and 126).

165. Considerable attention is paid overseas to the need to take special precautions where acidic wastes may occur or where there is the probability of attack by sulphuric acid derived from hydrogen sulphide in high ambient temperatures. In this country the number of sewer failures from chemical attack is limited and confined to certain areas. Our trade waste control is also, in general, effective so that we do not advocate the adoption of any of these special measures on a wide scale but commend them to the attention of those who have to design pipelines to convey industrial wastes or sewage containing trade discharges or where hydrogen sulphide attack is likely. (Paragraphs 70, 74 and 88).

166. Marston's work is still the basis of design in most progressive countries and the increasing use of mechanical excavation has tended to draw particular attention towards his wide trench theory. (Paragraph 98).

167. It is noteworthy that few countries are in advance of ours in the technical field of sewer design; in fact many countries follow British practice with local modifications to suit their particular circumstances. (Paragraph 126).

168. It is clearly undesirable that leakage from a foul sewer should enter a surface water sewer and imperative that leakage from either of these should not enter a water main. To try to prevent this from occurring some countries place their surface water sewers above their foul sewers and their water mains above all their sewers where these are in the same vicinity. Whilst these or similar measures are desirable, and indeed pipes are often laid in such a manner in this country, the additional expense of making them mandatory in our towns and cities is not justified. (Paragraph 84).

169. A number of countries have regulations controlling the construction of trenches to increase the safety of the workmen. The need to ensure the safety of men constructing works is not really restricted to sewer construction but extends to all civil engineering and building work both above and below ground level. In this country such work is subject to The Construction (General Provisions) Regulations 1961, which are subject to the interpretation of the Courts. Whilst these Regulations require a contractor to take steps to protect persons employed from a fall of earth they are not so specific in their requirements as those of some other countries. (Paragraph 89).

170. We have found that a number of countries prefer sand to gravel for bedding pipes and others take special precautions to prevent the granular material moving or becoming a drainage trench. In our *Note of Guidance on Practical Considerations in the Structural Design and in the Construction of Small diameter Sewers and Drains* issued with our second report we recommended the use of $\frac{3}{8}$ to $\frac{3}{16}$ in stone or gravel but suggested that certain coarse sand, or sand and gravel, or gravel from $\frac{3}{4}$ in down could be accepted if it passed certain tests. We still believe that these recommendations result in the best method of construction, but we will review the situation when more information is available. (Paragraph 93).

171. We understand that there is a trend towards vertical casting of concrete pipes in this country. Consideration may have to be given to whether the $\frac{1}{2}$ in cover specified in BS 556 is sufficient to ensure a satisfactory pipe where this method of manufacture is used.

172. We have been impressed by the research which is being carried out on a variety of aspects of sewerage design in many parts of the world. With the advent of a large number of plastics materials it is natural that some research has been diverted to investigating the properties of these materials which differ from those of the materials most frequently used. Materials such as these, which are resistant to most wastes and are light and smooth, clearly have considerable potential if the structural design problem can be solved. The tendency to creep with age and the permissible deformation must be examined closely, bearing in mind the expected life of the pipe. A further difficulty arises from the way the life and the permissible working stresses of plastics sewer pipes depend on the temperature of sewage. We shall pursue our investigations into the temperatures of sewage which occur in practice with the object of determining the worst

conditions which pipes should be designed to endure. Present design is based on a permissible deformation without adequate scientific evaluation of the deflection which should be permitted. Considerable research and experimental work will have to be carried out before we can give reliable advice on the design and laying of plastics pipes. (Paragraphs 113 to 124).

173. We shall endeavour to keep in touch with those conducting research into any aspect of structural design. (Paragraph 125).

Future role of the Working Party

174. We have been informed that the Department is initiating research into a wide range of subjects including sewerage, sewage treatment and water supply. Whilst our own terms of reference have been associated mainly with the structural design of sewers it is clearly desirable that research into this aspect of sewer design should be co-ordinated with all other aspects of the design of pipelines for carrying both water and sewage. We understand that you propose amending the terms of reference of the Working Party so that it will become a co-ordinating body to cover all facets of this subject.

175. We appreciate that with the widening of the terms of reference you will wish to review the balance of membership of the Working Party so that all interests in this wider field are properly represented. In order to facilitate this we are willing to place our resignations at your disposal so that you may make such changes in the constitution of the Working Party as you may consider desirable. In the meantime we shall, of course, continue with our task, which we find rewarding, of great interest and is, we believe, of national value.

We have the honour to be,
Sir,
Your obedient Servants,

Signed T. P. HUGHES
R. R. BEAUMONT
GRANVILLE BERRY
R. T. GILLET
I. H. HAINSWORTH
JOHN M. HASELDINE
H. P. KAUFMAN
R. V. LINDSLEY
J. B. STOREY
R. W. C. YEO
O. C. YOUNG

T. W. G. HUCKER
T. C. GEORGE
Secretaries
17th February 1971

APPENDIX

Reports on sewerage design in other countries

Europe

Austria

A1. The main sewerage system of Vienna was constructed in the 1840's and many of those well built and generously designed sewers are still in use. The larger part of the city is drained on the combined system, the separate system being confined to the south of the town. In some lower-lying areas surface water soaks into the sub-soil.

A2. Sewers are constructed of pre-cast concrete or clayware pipes or of in-situ concrete. Circular pipes have a minimum diameter of 200 mm and a length of 1 m. Egg-shaped pipes are manufactured with dimensions 400/600 mm, 500/750 mm, 600/900 mm, 700/1050 mm, and 800/1200 mm, with a length of 1 m. Socket and spigot or ogee joints are used. Egg-shaped sewers are also constructed of cast in-situ concrete with dimensions 700/1050 mm, 800/1200 mm, 900/1350 mm, 1000/1500 mm, 1100/1650 mm and 1200/1800 mm. Ovoid sewers frequently have 250 to 300 mm thick vitrified clay tiles, both flat and curved, at the inverts and the largest sewers have brick inverts. Small sewers up to 400 mm diameter are constructed in clayware. Unplasticised polyvinyl chloride (pvc) pipes have been used for some years for the construction of combined drains up to 200 mm diameter.

A3. To avoid frost penetration sewers are constructed at minimum depths of 3 to 4 m in cities and 2 to 2·5 m in rural areas. They are frequently laid under the centres of streets. Sewers are designed on the basis of 250 litres of flow per person per day and to convey stormwater from a once in 1½ to 2 years storm with minimum velocities of 0·5 m/s.

A4. If sewers are laid in a trench with a clay, loam, stony or wet base a bedding of 100 mm of dry sand or lean concrete is provided. Smaller pipes are bedded and haunched with concrete, minimum 50 mm thick. Trenches 800 mm wide have vertical walls but the walls of trenches 1 m wide for 200, 250 and 300 mm diameter pipes taper over the deepest 0·6 m to a width of 0·7 m. Those for 350 and 500 mm pipes taper from 1·0 m to 0·8 m over the deepest 0·4 m. Pipes may be surrounded with concrete if the loads are high.

A5. Many sewerage systems are constructed with a circular foul sewer below the side of an oval surface water sewer. The lower pipe may be surrounded with concrete for the full width of the trench and carried up to the centre line of the upper pipe. Sometimes the excavation under the upper pipe is cut at an angle of

45° to reduce the amount of concrete. Manholes on the foul sewer are constructed beside the surface water sewer. If both sewers are circular the surface water sewer is located above the foul sewer and a double manhole is built with a reinforced concrete dividing wall 100 mm thick.

A6. Trenches are backfilled with sandy material without mechanical compaction for a depth of 300 to 500 mm above the pipe. Backfilling is carried out in 150 to 200 mm layers, the strutting of the trench sides being dismantled as backfilling is carried out.

A7. It is recommended that manholes on foul sewers be constructed of precast or in-situ concrete at 35 m maximum spacing where pipes cannot be entered and 80 m maximum spacing where pipes can be entered. Access shafts are generally 600 × 600 mm and chambers are 1650 mm high by 800 mm wide with a curved roof. Sewers are ventilated through the manhole covers, the street inlets and the downpipes.

A8. There are a number of national standards. One is for inspection chambers on house drains and shows them as 400 × 600 mm or a diameter of 600 mm internally where the cover above the drain is less than 600 mm; 600 × 600 mm or 600 mm diameter where the cover is between 600 and 800 mm; 600 × 1000 mm or 1000 mm diameter where the cover is between 800 and 1500 mm and 1200 × 700 mm or 1000 mm diameter where the cover is greater than 1500 mm. Chambers have a shaft 600 × 600 mm or 600 mm diameter and a minimum height of 1·2 m in the last named locations. If the depth is more than 0·8 m, step irons at 0·3 m spacing are provided. Benching of chambers has a fall of 3%. The minimum size of drain is 100 mm for surface water and 150 mm for foul sewage.

A9. Pvc pipes are supplied with sockets and joint rings or adhesive sleeves and in lengths of 3 to 6 m in diameters of 32, 40, 50, 75, 100, 125, 160 and 200 mm. They are laid on a bed free of stones. On steep slopes measures are taken to prevent the washing away of the bedding material. The pipes are not considered suitable for constant or intermittent discharges of water with temperatures higher than 60°C. A local Act in Vienna forbids the discharge of sewage warmer than 30°C, and trade wastes hotter than 60°C must be cooled by passing through tanks before discharge.

A10. Surface water sewers have a minimum diameter of 200 mm and combined sewers a minimum diameter of 250 mm. Clayware or concrete pipes may be used for surface water sewerage but the latter are considered to have limited resistance against chemical attack and abrasion. The resistance can be increased by painting the pipes with a fluoride based paint or bitumen. Sewers are also made of in-situ concrete, reinforced concrete or brickwork. In-situ sewers have a radius of curvature of at least 10 m. Surface water discharge from domestic premises is at least 100 mm above the invert of the sewer and preferably not above half the profile height. It is discharged at an angle not greater than 45° to the direction of flow. Concrete sewers contain a minimum of 180 kg/m^3 of cement. Special cements including blast furnace cement are used if the soil or groundwater is aggressive, and additives are used to improve resistance and aid compaction. Some concrete sewers are lined with clinker bricks, clayware or concrete mould pieces. Brick sewers are constructed with clinker bricks. Manhole shafts should not exceed 35 m spacing if the pipes are rough or 80 m if they are smooth. Pipes are constructed in straight lines between chambers. Surface water manholes have a chamber measuring at least 1 m diameter or 700 × 1200 mm, a minimum height of 1·5 m and a shaft of 600 mm diameter. Flushing chambers are provided where deposits are likely to occur and snow slit shafts are designed with a constantly increasing cross section in a downward direction to prevent snow piling up. Siphons are constructed with at least two pipes and with cleansing chambers at each end. Sand traps are built at the inlets of siphons.

Czechoslavakia

A11. Sewers are normally constructed of glazed vitrified clay (gvc) pipes, reinforced concrete pipes, concrete pipes, in-situ concrete, brickwork or pre-cast reinforced concrete units. Brick sewers are constructed circular or egg-shaped. Asbestos cement pipes and cast iron pipes are sometimes used. Pvc pipes are used for building drainage, and steel pipes are used where pressures and velocities are high. Gvc pipes are manufactured 1 m long in diameters of 100, 125, 150, 200, 250, 300, 350, 400, 500 and 600 mm. Plain concrete socket and spigot pipes are vertically cast in diameters, 100, 150, 200, 250, 300, 400, 500, 600 and 1000 mm and lengths of 1 m. Butt-jointed plain concrete vertically-cast pipes are manufactured in diameters of 150, 200 and 300 mm with lengths of 1 m and in diameters of 400, 500 and 600 m with lengths of 0·75 m. Reinforced concrete spun socket and spigot pipes are produced in diameters of 300, 400, 500, 600, 700, 800, 1000 and 1200 mm and lengths of 4 and 5 m. Reinforced concrete, plain ended, vertically-cast pipes with octagonal outside profile are manufactured in diameters of 300, 400, 500, 600, 800 and 1000 mm, and lengths of 1 m.

A12. Socket and spigot joints are used for gvc pipes, reinforced concrete pipes, asbestos cement pipes and cast iron pipes. Gvc pipes are normally jointed with bitumen although some preformed rubber joints are now being used. Reinforced concrete pipe joints are sealed with rope and cement mortar although it is realised that the quality of the jointing in the lower part of the joint is not always satisfactory.

A13. Clayware, plastics or brick linings are used at the inverts of brick or in-situ concrete sewers.

A14. Sewers have a minimum diameter of 300 mm or 250 mm if constructed of clayware although smaller diameters are used for house drainage and connecting pipes. Sewers are designed to have a maximum velocity of 10 m/s if constructed of clayware or brickwork and 5 m/s if constructed of concrete and reinforced concrete but concrete inverts should be lined if the velocity exceeds 3 m/s. Plain concrete pipes are only used for surface water and temporary works. The calculation of the load applied to a sewer is based on Marston's theory or Klein's method.

A15. Sewers are usually constructed at depths between 2·5 and 4·0 m. Sewers in Prague are laid below water mains which are at least 1·5 m deep and as a result sewers in that town are usually at least 3 m deep.

A16. The standard for laying gvc pipes with diameters 200, 250, 300, 350, 400, 500 and 600 mm specifies trench widths according to whether the depth of cover over the pipe is limited to 4 or 5·5 m. A wider trench is used for the greater depth. Seven different types of bedding are listed for trenches with vertical walls. Pipes up to 350 mm diameter are normally laid on a levelled trench bottom if it is soft. If the bottom of the trench is rock a further 150 mm has to be excavated and replaced with sand. When laying in dry trenches, pipes up to 500 mm diameter may be laid on sand or surrounded with concrete. The concrete surround extends for the full width of the trench and its top slopes down from the pipe to the trench walls. For larger pipes it is 150 to 200 mm thick. It is placed in one operation, the pipes being supported on pre-cast concrete blocks. Transverse joints may be provided in the surround dependent on site conditions. Pipe joints are normally sealed with hot poured bitumen. A rubber band smeared with clay may be used in the joint as an alternative to rope.

A17. For pipes bedded on sand the standard suggests that backfill should consist of graded earth or sand with a maximum grading of 30 mm compacted in layers up to 150 mm thick for the first 300 mm above the pipe. The remaining backfill for all pipes should consist of spoil from the trench and be compacted in layers not exceeding 300 mm thick. Machine compaction is permitted where the cover is greater than 0·7 m for sewers with graded backfill or 1 m for sewers with concrete surround.

A18. Concrete pipes are laid on a levelled trench bottom, a concrete bed or on concrete sleepers placed longitudinally with or without a concrete bed. The top of the concrete bed falls from the pipe centre to the trench walls for pipes up to 6·5 m deep. At greater depths the top of the bed is horizontal at the level of the centre of the pipe. In wet conditions trenches are drained by land drains, usually 65 to 100 mm diameter, in a granular bed about 200 mm deep. Trenches up to 800 mm above the crown of the pipe must be filled with selected material in layers 200 mm thick, slightly rammed. Above this, material is rammed in 300 mm layers. Water may be used to aid compaction if sand is used for backfilling trenches.

A19. Jointing, backfilling and compaction are often at variance with the standards and in the majority of cases trenches are backfilled by dozers.

A20. About 5% of the overall length of sewers are constructed in-situ. Inflatable cores of plastics introduced 10 years ago are often used for 250 to 2000 mm diameter pipes and for non-circular sections. Cores 16 and 10 m long have been used. Egg-shaped brick sewers are favoured by the authorities in Prague and Pilsen but contractors prefer in-situ reinforced concrete sewers.

A21. Manholes are constructed at the head of sewers, where sewers change direction, at junctions and where connections 250 mm diameter and over join. In addition they are located at maximum spacings of 50 m on sewers up to 1500 mm diameter and maximum spacings of 100 m on larger sewers. Change of direction by constructing a curve outside an inspection chamber is permitted on sewers 800 mm diameter and above, normally at a radius of 10 times the diameter of the sewer but with a minimum radius of 5 times the diameter of the sewer. The lower part of manholes are constructed of in-situ concrete and the remainder of the chamber above water level of precast rings 1000 mm diameter and 300 mm high, the uppermost ring tapering unsymmetrically with a vertical side to a diameter of 700 mm at the access cover. Chambers with back drops are lined with brickwork.

A22. Some sewers are constructed using tunnelling shields.

A23. There are standards for cast iron pipes and fittings, concrete pipes, reinforced concrete pipes, asbestos cement pipes, gvc pipes, drainage systems and house connections, shapes and dimensions of sewers, and maintenance and operation of sewerage systems. There are seven standard profiles for egg-shaped sewers from 600/900 to 1800/3150 mm.

A24. The universities are part of the civil service so that there is good contact between them and the Ministry of Building.

A25. Research and theoretical investigation into sewer laying appears to be considerably in advance of practice. Methods of relieving stress by bridges, blocks and cushions have been investigated. Photoelastic methods were used to test a model of a bridge over a pipe. This system was adopted for a scheme including 2 km of reinforced concrete pipes and is claimed to give a bearing capacity 3 times greater than that required. Tests with a cushion have shown a reduction of 30% to 70% of pressure on the crown of a pipe compared with simple backfilling. The application of inflatable cores has been extended to the concreting of chambers. Concrete sewers with reinforced lining are now preferred to brickwork sewers. Rubber joint rings are being introduced to all types of sewers.

Denmark

A26. Sewer construction is the responsibility of local authorities. Pipes used include:

(a) unreinforced concrete circular pipes from 100 mm to 1000 mm diameter and various lengths up to 1 m manufactured to Danish Standard 400·3·1;

(b) unreinforced concrete circular pipes with a curved protruding invert of small radius and flat base from 350 mm to 1000 mm diameter and in lengths from 0·6 to 1 m manufactured to Danish Standard 400·3·8;

(c) unreinforced concrete pipes, for use with rubber joint rings, in lengths up to 2 m; and

(d) reinforced spun concrete pipes from 300 mm to 2500 mm diameter in lengths up to 5·4 m; the longer lengths are only available in the smaller diameters; bends and manhole shafts cast with the pipe are listed.

There are standards for rubber ring joints.
A code of practice on concrete sewerage pipes is being completed and one is being prepared on various aspects of plastics pipes for sewerage and drainage.

Finland

A27. Sewers 300 mm diameter and above are usually constructed of concrete pipes although some 300 mm and 400 mm diameter glazed clay sewers are used to resist attack by acids.

A28. A standard for reinforced concrete pipes covers:

(a) socket and spigot pipes from 100 mm to 400 mm diameter and from 0·800 to 1·06 m length;

(b) ogee jointed pipes with diameters 300 mm and 400 mm and lengths 1·017 m;

(c) circular pipes with diameters 400 mm to 1800 mm and lengths from 1 m for the smallest size to 0·6 m for the largest size;

(d) 45° and 85° bends for (a);

(e) saddle pieces for (a) with diameters 100 mm to 226 mm;

(f) tees for 100 mm to 300 mm diameter pipes;

(g) Y branches for 100 mm to 400 mm diameter pipes;

(h) manhole chamber rings with ogee joints, diameter 600 mm to 2000 mm and length 0·5 m;

(j) manhole taper rings; some of these are tapered unsymmetrically on all faces, but others have 1 vertical face;

(k) chamber base rings;

(l) chamber covers with 2 access holes; some of these have a built in lifting ring;

(m) chamber covers with one access hole;

(n) chamber covers without any access hole; and

(o) flat-based circular pipes from 800 mm to 1800 mm diameter.

The standard specifies tolerances on the dimensions and the positions of reinforcement in considerable detail. The dimensions of the joints are detailed. Examples are given of the construction of pipes under railways, in ducts, and on concrete rafts. Concrete surround is shown with the top falling at 1 in 20 to to the sides. There is a separate standard for pipes with rubber joints covering pipes with diameters from 100 mm to 1200 mm and lengths up to 2 m.

A29. Regulations controlling the location of various services in streets have been published. These show the positions of the services in the different types of highway and indicate that sewers should be placed under the edge of the highway (or service road) adjacent to the water and gas pipes.

A30. Pipes are laid on the trench bottom with holes dug out for sockets, or supported off the trench bottom on folding wedges or rubble. Pipes are bedded on sand, gravel or concrete and may be supported on planks on timber poles surrounded by sand. Pipes up to 400 mm diameter are bedded on gravel or on a sandy mixture, those up to 800 mm on a concrete, gravel or stone base and larger pipes on a concrete base. Concrete slabs are used to support pipes above 400 mm diameter on loam or marshy soil.

A31. Many types of flexible joint are used. Pipe joints are also jointed with clay if in a clay stratum or with cement mortar if the socket is lined with bitumen.

A32. Manholes for sewers less than 600 mm diameter are constructed of concrete rings and those on larger sewers are constructed of in-situ concrete. They are located at the heads of sewers, at changes of diameter, direction and gradient, where sewers join and at maximum spacings of 50 to 70 m.

A33. The Finnish Technical Research Establishment have examined the performance of polythene and polyvinyl chloride pipes at 23°C and 5°C. Investigations have been instituted into the effects of traffic loading and they showed a tendency to a greater increase in deformation with time as the thickness of the pipes decreased.

France

A34. Instructions have been issued by the Ministry of Equipment covering sewer construction in urban areas and by the Rural Management Section of the

Ministry of Agriculture covering sewer construction in rural areas. It is intended to combine the two documents. Each document is supplemented by a particular specification where necessary.

A35. The Ministry of Equipment instructions, which have many similarities to those of the Ministry of Agriculture, cover unreinforced concrete pipes up to 800 mm diameter, reinforced concrete pipes up to 1800 mm diameter, ovoid sections, asbestos cement pipes up to 800 mm diameter, clayware pipes up to 600 mm diameter, steel pipes and pvc pipes. The Ministry of Agriculture publication covers unreinforced concrete pipes and reinforced concrete pipes both up to 1200 mm diameter. Pipes are laid on a trench bottom, regulated with fine soil, holes being excavated in the trench bottom for sockets. Excavation in rock etc. has to be carried down at least 100 mm below the bottom of the normal excavation and backfilled with fine material. Tarred rope and bitumen or, preferably, rubber joint rings are used to joint clayware pipes. Manufacturers are testing out a polyurethane joint. Cement mortar joints are not used.

A36. In the Ministry of Equipment booklet the required ultimate strength of the pipe is calculated from multiplying the load by a safety factor between 2 and 2·7. The load is obtained by multiplying the pipe diameter by the pressure of the fill plus the pressure produced by a wheel load of 6500 newtons* and dividing by a bedding factor of between 1·1 and 2·3 depending on the effective angle of support. The safety factor is raised to 3·5 for pipes which are not to an approved standard. The Ministry of Agriculture booklet specifies a safety factor of 3 for concrete pipes unless otherwise specified in the particular specification, and leaves the class of clayware pipe to be covered in that specification. Another widely used booklet, issued by the Ministry of Reconstruction and Town Development in 1949, recommends methods of sewerage design.

A37. In separate systems, sewers are not less than 150 mm diameter and branches not less than 120 mm or exceptionally 135 mm diameter. For surface water sewers and combined systems minimum diameters of 250 mm or even 300 mm are adopted. Oval sections, which are preferred for variable flows, are at least 500 mm wide.

A38. There is a dimensional standard for oval sewers varying from 1000 mm by 625 mm to 2000 mm by 1200 mm with tolerances depending on the material used.

A39. The standard for asbestos cement underground sewer pipes conforms to International Organisation for Standardisation (ISO) recommendations and covers pipes from 1250 mm to 800 mm diameter with lengths of 4 or 5 m. There are two classes of pipe. Series A_1 standard strength pipes, have a crushing strength of 5800 daN/m^2 and Series A_2, extra strength pipes, have a crushing strength of 8830 daN/m^2. These correspond approximately to loads of 6000 and 9000 kgf/m^2 respectively. The absorption of the pipes is not allowed to exceed 0·001 cm^3 per cm^2 surface area per day. There are standards for ¼ bends, ⅛ bends, single 45° branches, double 45° branches, T's, S's and tapers in both standard and extra strength series. The specials are from 800 to 5000 mm diameter. There is also a standard inspection fitting.

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*A newton (N) is a unit force derived from the equation 1 kg = gN where g is the acceleration due to gravity. (1N = 0·102 kg = 0·225 lbf).

A40. The standards for concrete and reinforced concrete pipes cover pipes with diameters of 80, 110, 165, 225, 280, 335, 390, and 450 mm.

A41. Manholes are usually constructed of in-situ concrete but precast manholes are being used more frequently. In Paris manholes are built of brickwork or masonry. They are provided at all junctions and at changes of section, slope and direction and at the ends of sewers. Manholes are frequently spaced a maximum of 50 to 60 m apart. A recent paper from the Ministry of Building and Public Works advocated a maximum spacing of 60 m for 200 and 300 mm diameter pipes and 80 m for larger pipes. The larger spacings depend to some extent on the availability of cleaning equipment such as high pressure jetting.

A42. Tests have been carried out to study the behaviour of buried pvc pipes by subjecting them to a maximum of 301,000 passages of a transient load, attention being directed to the diameter and thickness of the pipes, the nature of the surround and the width of the trench. 400 and 200 mm diameter pipes were laid under a circular track and a twin wheel load of 8 tonnes* rolled along the track at a speed of 23 km per hour. Pipes 4, 6 and 8 mm thick were used under 0·4, 0·8 and 1·2 m of earth. It was considered that the experiments reproduced the loading conditions on a road subject to medium traffic during a period of 4 to 5 years. It was concluded that the height of the embankment or filling was most important and that deformations increased when the pipe thickness decreased. Ovality diminished as the depth increased but the vertical diameter increased and the horizontal diameter decreased when pipes were buried at a depth of 0·4 m due to compaction of the pipe surround.

Holland

(a) Generally

A43. Concrete and pvc pipes are normally used for sewers but limited quantities of small diameter asbestos cement and cast iron pipes are also used. Prestressed concrete pipes are usually used for large sewers and where soil conditions are bad. Pitch-impregnated fibre pipes are being introduced on a small scale for pipes of 300 mm diameter and under where the soil gives poor support. House and street drainage are constructed of 125 mm external diameter pvc pipes, vitrified clay pipes or occasionally concrete pipes. Concrete pipes are said to be the cheapest pipes and are available 1 m long in the following diameters: 300, 400, 500, 600, 700, 800, 900, 1000, 1250 and 1500 mm. Many sizes are also available 2 m long. Until a few years ago, flat based 1 m long pipes of the same diameters were in use. Reinforced concrete pipes are preferred where railway lines or important roads are crossed. The use of asbestos cement pipes and pvc pipes is limited to diameters of 500 mm and less due to their high cost in the larger sizes. Cast iron sewers are believed to be used only in the city of Amsterdam.

A44. There are standards for a wide range of clay, concrete and plastics pipes.

A45. Where the subsoil consists of peat, special measures have to be taken such as the use of wooden bearing piles with concrete or wooden cross beams to support concrete, reinforced concrete, prestressed concrete and asbestos cement pipes. Where the ground is soft, pipes may also be laid on wooden frames. Pitch fibre pipes are considered suitable for use in soft ground without pile supports.

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*1 ton = 1·016 tonne.

A46. Concrete pipe joints are made with rubber rings. Those consisting of a collar of cement mortar or bitumastic putty are no longer used and those in which a bituminous strip is fixed on to the spigot of each pipe and heated are rarely used. Pvc pipes used for house drains were formerly jointed with rubber rings made of natural rubber, but in view of the alleged risk of these being affected by streptomycin fungus they have now been superseded by synthetic rubber rings of styrene butadiene rubber (sbr), butyl or nitrile rubbers. Vitrified clay pipes are jointed with sbr rings of two types, round foam rings and rings with flanges, to stand a minimum internal and external hydrostatic head of 5 m. In Holland these pipes are considered by some to have the disadvantage that due to pipe irregularities, joints are not always watertight and to be dearer per metre than pvc pipes. Vitrified clay pipes are, however, preferred where the water is agressive or where plastics pipes are liable to excessive deformation. Pvc and asbestos cement pipes may have a collar type joint.

A47. Concrete pipe design criteria are being revised so that the pipes must withstand a test load derived from a distributed load of 8 tons per square metre equal to a total of 30 tons or three 10-ton axle loads the pipes being laid at a depth of 1 to 3·5 m. This will require an increase in pipe thickness for some of the larger pipes.

A48. Sewers are frequently laid under the crown of a road and as a result heavy traffic bears directly on the pipes. There is a further disadvantage in locating pipes in this position in that repair work involves breaking up the road. Pipe trenches are usually constructed 0·25 m wider than the outside diameter of the pipes and with a side slope of four vertical to one horizontal. In clay a layer of gravel is sometimes laid under the pipes. This has a dewatering function but soil may seep into the voids, thus weakening the lateral support and result in the sewer breaking under heavy traffic. A loose sand bedding is therefore preferred. Trench bottoms are trimmed and filled with bedding materials where necessary. Pipes on pile foundations must be capable of bearing concentrated loads and there must be no pipe joint at the point of support. Normally the soil in a trench is compacted to 98% to 100% Proctor density but it is considered undesirable to compact the soil directly above sewers, particularly if the pipes are of pvc.

A49. Manholes are constructed of masonry or precast concrete with cross section 0·9 × 0·9 m or 0·8 × 0·8 m if the pipes are 300 mm diameter or less. Larger manholes are greater than 0·9 m in one direction. Manholes are normally spaced a maximum of 50 m apart but this may be increased to 70 m if maintenance facilities permit. Manholes are usually installed at the head of main sewers, junctions, changes in diameter, direction and gradient, although junctions and inspection pipes in a brick chamber are sometimes used for the connection of small diameter branches. Curved sewers are not allowed.

A50. House drains and gullies are connected to concrete sewers by a concrete casing on the top of the sewer; if the sewer is of pvc then pvc piping is used for the connection. If two sewers are laid beside one another in a road then the larger sewer is constructed with concrete pipes and the smaller sewer with 160 mm diameter pvc pipes and inspection junctions for the connection of house drains. It is considered essential to have some degree of flexibility at connections with manholes. Sockets are built into the walls of manholes to obtain the same type of joint as that between two pipes or short pipes are used adjacent to the manholes.

(b) Detailed information on Amsterdam

A51. In the city of Amsterdam 3000 hectares (11·5 square miles) with 490,000 inhabitants are drained on the combined system and 3000 hectares with 360,000 inhabitants on the separate system. Small areas discharge sewage to open water. 870,000 inhabitants produce 56 million cubic metres of waste water per annum at the rate of 112 litres per head per day (i.e. 25 gallons per head per day). The city has:

70 km	main and branch sewers (on pile foundations)
70 km	connecting or trunk sewers (on pile foundations)
35 km	*polder sewers
1800 km	sewage and surface water drains
60 km	pressure pipelines

The soil consists of imported sand, to a height generally 1·3 m above ground water level. Below the original ground there is a mixture of clay and then clay with sand to a depth of 10 m. At a depth of 11 to 12 m a more stable layer of sand is found. The ground water is frequently only 0·2 m below the original ground level.

A52. The main sewers of the combined system are situated at a minimum of 1·7 m below street level and fall to a maximum of 4 m deep at pumping stations. They are constructed of cast iron pipes 300 to 600 mm diameter and 5 to 6 m long beside canals, or reinforced concrete pipes 400 to 800 mm diameter and 3 to 3·6 m long elsewhere, and are normally laid at a gradient of 1 in 750. The cast iron pipes are supported on a pile foundation. Egg-shaped sewers are no longer used.

A53. Sewers serving individual streets are constructed of 300 to 600 mm diameter concrete pipes 2 m long with rubber ring joints at gradients up to 1 in 500. The pipes have a minimum cover of 0·75 m and are a maximum of 1·8 m below street level. Polder sewers are generally similar to street sewers consisting of reinforced concrete pipes but at a minimum of 2 m below street level. Pile foundations are not usually used for serving individual streets or for polder sewers.

A54. Rising mains are constructed of cast iron pipes 150 to 800 mm diameter in 5 to 6 m lengths.

A55. The main sewers of the separate system are also normally laid at a gradient of 1 in 750, to obtain some self cleansing conditions, although this gradient is not always achieved. A sewer 3000 m long with a diameter increasing from 400 to 700 mm has been laid, with gradients from 1 in 750 to 1 in 1500, the cover increasing from 1·5 m to 3·8 m. Very deep sewers are not constructed. The trunk sewers are 400 to 800 mm diameter, the smaller pipes being cast iron 5 to 6 m long with rubber ring joints and the larger pipes being reinforced concrete. Pipes are frequently supported on two timber piles and a yoke of reinforced concrete. They are usually below the ground water level. Manholes are normally of precast concrete, and are supported on 4 piles, the upper part having brick walls where there are house connections.

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*Polder sewers are sewers constructed below the original sea level.

A56. Foul sewers are constructed of 250 to 400 mm diameter concrete pipes 1 to 1·5 m long with rubber ring joints, at a gradient of 1 in 500. The pipes are laid with a cover of 0·75 to 1·45 m and are usually above the ground water level and pile foundations are not necessary. Manholes are 660 by 440 mm in section and are constructed with a reinforced concrete base and masonry walls.

A57. Surface water sewers are constructed of 300 to 400 mm diameter concrete pipes 1 m long and 500 to 1000 mm diameter concrete pipes 2 m long at gradients up to 1 in 1000. They are located at depths between 0·7 and 1·1 m at or just above the ground water level. Manholes of pre-cast reinforced concrete rings to which clinker blocks are mortared are constructed at 20 m intervals. Pile foundations are not constructed under surface water sewers but concrete planks 3 m long are used to support 300 to 400 mm diameter pipes.

A58. House connections are constructed of 125 mm diameter glazed vitrified clay pipes 1 and 1·25 m long under footways, and 125 mm diameter cast iron pipes 5·5 m long under roads.

Republic of Ireland

A59. Sewer construction in Ireland is similar to British practice. Up to a few years ago sewers were bedded and haunched in the traditional manner and concrete surround was provided where the cover was less than 3 ft 6 ins under roads. Very few structural failures have been reported. In recent years considerable lengths of sewer of both large and small diameters have been laid on granular bedding. Small diameter sewers are constructed of stoneware or concrete pipes but some lengths of pvc and asbestos cement pipes have been laid. Larger sewers are constructed of concrete pipes, plain or reinforced. A few experimental lengths have been constructed of glass fibre reinforced concrete pipes. Gradients are normally selected to limit the maximum velocity to 10 ft/s but there are known instances of concrete pipes with velocities up to 20 ft/s showing no significant damage after many years of service.

Italy

A60. These notes are based on detailed information on the sewerage of Milan. Sewers up to 400 mm diameter are built of ovoid or circular clayware pipes. Sewers with major dimensions of 600 to 2300 mm are constructed of in-situ concrete with a granolithic invert and brick lining of the adjoining wall areas. Larger ovoid sewers are constructed similarly of lined mass concrete with semi-circular soffits and large radius inverts. Sewers up to 2000 mm wide and 3000 mm high may be constructed in the British egg-shaped section. Small pipes are laid on and haunched with concrete, the top of the latter being tangential to the top of the pipe and having an angle of 30° to the horizontal. A small subsoil water drain is constructed under large sewers.

A61. Sewers have been damaged, particularly at the invert, by acidic trade wastes and considerable thought has been given to this problem. As a result, there has been a tendency towards plastics or epoxy resin lined mass concrete sewers or similar sewers surrounded with concrete with hooped reinforcement. Some sewers have a semi-circular invert constructed of acid resistant material below the normal circular profile.

A62. The municipal sewerage regulations give minimum and maximum gradients for each size of clayware and concrete pipe. Sewers less than 300 mm diameter are only permitted in exceptional cases. Manholes are required at maximum distances apart of 50 m for sewers which can be entered by a man and 30 m for sewers which cannot be entered. Manholes are rectangular with a shaft in one corner and have minimum dimensions of 1·0 m × 1·2 m × 1·7 m. They are located at changes of direction, gradient and section, at junctions of longer branches and at all special construction. Branches are connected just below the tangent point of the roof curve, the brick invert being carried up to the level of the discharge pipe. Connections are normally at least 150 mm diameter for separate systems or 200 mm for combined systems.

Russia

A63. Water, gas, sewerage and district heating services are frequently constructed in large prefabricated underground ducts consisting of a bottom unit, 2 inverted L shaped wall blocks and a deck slab.

A64. Pre-cast reinforced concrete pipes with diameters 1700 to 3500 mm have joints sealed with polymer plastics to reduce the number of constructional operations. Some of the larger pipe joints are sealed with phenoaldehyde monomer and epoxy resin. The mastic remains impervious to water at high pressures and resists salt solutions, alkalis and acids. Considerable lengths of sewer have been constructed using tunnelling shields 2000, 2250 and 4000 mm diameter.

A65. Prefabricated manholes are used as they take $\frac{1}{3}$ to $\frac{1}{2}$ of the labour time of brick or cast in-situ manholes.

Spain

A66. Sewers are constructed of vitrified clay, plain or reinforced concrete or plastics pipes. Vitrified clay and concrete pipes are required to withstand a 3 point load test of 1000 kgf/m.

A67. Large sewers in Madrid are constructed with vertical brick walls, a flat in-situ concrete invert and a semi-circular brick soffit, all brickwork being rendered. 900 mm wide sewers have a semi-circular channel 400 mm wide on one side and a flat benching on the other side. Sewers 700 mm wide have a slightly curved invert falling to a low point on the side or the centre. Larger sewers up to 3000 mm high, and 2400 mm wide have curved walls and some have a semi-circular channel up to 650 mm wide.

Sweden

A68. Although there are no official codes of practice for the design and construction of sewers, a joint committee appointed by the interested associations has compiled a general specification for material and workmanship for water supply and sewerage pipelines in considerable detail. This specification is supported by standards for concrete and gvc pipes. Standards for plastics pipes are being prepared. The general specification is being revised to include construction on housing estates.

A69. In recent years 95% of sewers have been constructed of concrete pipes, 1·5% of gvc and the remainder have been mostly of plastics pipes. Gvc pipes are no longer manufactured in Sweden but are imported.

A70. The standard for concrete pipes covers socket and spigot pipes from 100 mm to 400 mm diameter, although the smallest pipe normally used for sewers is 150 mm diameter. Ogee joints are listed for unreinforced pipes from 225 mm to 400 mm diameter and for reinforced pipes from 500 mm to 2000 mm diameter. Flat-based pipes are also specified. Specials include 85° bends, 45° junctions, tapers, saddles and gully pots. Although the standard was based on the use of cement mortar joints, rubber ring joints are normally used. Pipes in the standard are not intended to be buried at depths greater than 7 to 8 m. Concrete manhole rings vary in diameter from 900 mm to 1500 mm. Taper rings have a vertical side reducing to 600 mm diameter. Cement mortar joints are specified in detail.

A71. The standard for socket and spigot gvc pipes covers:

straight pipes from 100 to 600 mm diameter, in lengths from 0·6 to 1·0 m, although pipes 225 mm and greater in diameter have a minimum length of 0·75 m;
85° and 45° bends for pipes 100 to 400 mm diameter;
T's 600 and 750 mm long;
Y's 600 and 750 mm long;
tapers; and
gullies.

The deviation from straightness is not allowed to exceed 8 mm for 0·6 m long pipes, 10 mm for 0·75 m long pipes and 13 mm for 1 m long pipes. Socket and spigot gvc pipes should be laid at least 1 m below streets and may be laid up to 3 m deep without special precautions. If the width of the trench is greater than 0·7 m, pipes may be used at greater depths, normally up to 5 m, provided the back filling is compacted with a soil rammer and water spray or a comparable method up to a height of half the diameter above the pipe. Pipes are required to stand a hydrostatic pressure test of 0·5 kgf/cm^2 for 15 minutes without signs of leakage and a crushing test of 3200 kgf/m for 100 mm diameter pipes rising to 3600 kgf/m for 600 mm diameter pipes.

A72. The minimum width of trench given in the Associations' specification is intended to give sufficient space for work. Pipes may be laid on the trench bottom if it is even and has no stones or boulders but if the bottom is rock, stony or uneven, excavation is carried down to 0·15 m below the pipe and replaced with coarse grained fill. If the load carrying capacity of the trench bottom is inadequate, longitudinal planks or in-situ concrete slabs are used to support the pipe bed. The concrete slabs are supported by piles of concrete, wood or steel where necessary. Concrete surround is not commonly used.

A73. Trenches are backfilled up to 0·3 m above the pipe with material which is compactable but not frost susceptible; gravel and sand being preferred. Above this depth the excavated material is used provided it does not consist of topsoil, peat or slime and mud. Particular attention is paid to compaction up to the invert of the highest pipe where more than one pipe is laid in a trench, to the top of small pipes and to the centre line of large pipes where the pipes are so deep that support from the surrounding fill is necessary to carry the load and where settlement of the backfill cannot be permitted, i.e. under streets. In both the last named locations carefully controlled compaction must be carried out up to surface level. Compaction is carried out to 90% Proctor density and a table showing the necessary number of passages of various types of equipment in different soils is given. Recommendations are also given for the minimum protection over pipes before machine compaction may be used.

A74. The depth of frost penetration is considered when determining the minimum laying depth. In fine sand the maximum frost penetration is 1·2 m in the south of Sweden and 4 m in the north. In certain soils the depth of laying can be reduced by taking account of the heat of the sewage.

A75. Rubber ring joints are designed to ensure a relative compression of the rubber ring of 20 to 50%.

A76. Manholes are constructed at all junctions, although connections are normally by a branch pipe; at every change of direction; and at a maximum spacing of 70 to 100 m. It is considered that the introduction of high pressure flushing equipment would allow the permissible spacing to be increased to 120 m. Manholes are constructed of factory made concrete rings. They are usually 0·9 to 1·0 m diameter but can be prefabricated up to 2 m diameter. A few large manholes are built in-situ. Manholes having rubber ring joints, with the bottom part including the junctions prefabricated, are becoming more common. Instructions for testing manholes with a hydrostatic head of 1 m are being prepared.

A77. The Swedish Association of Civil Engineers has published detailed instructions on sheeting of sewer trench walls.

A78. Sewers are tested with water or air. Water testing is carried out with a hydrostatic head of 1 m for a period of 10 minutes. Air testing is carried out to a pressure of 0·10 kgf/cm^2 (0·10 bar) corresponding to a hydrostatic head of 1 m. Air testing is preferred to water testing because of its speed and simplicity.

A79. Research work has been continuing since 1963 on the design and construction of plastics underground sewer pipes. One station has been engaged on geotechnical investigation, one on experimental trials in soil boxes and verification of formulae using materials of different rigidities and one on tests of materials to establish stress/strain relations as a function of time and to estimate the durability of pipes. The object of the research has been to prepare an installation guide and settle the limits of stress and deformation for sewers. A maximum cover of 4 m and limited percentage deformation after backfill are proposed, the latter depending on the initial deformation of the pipes and joints. The permissible deformation allows for an increase of the deformation as the pipe bedding compacts. Limits of pipe rigidity (thickness/diameter) are also recommended based on the material and the traffic on the assumption that there would be a minimum of 1 m cover under roads. It is also assumed that continually flowing sewage would not normally have a temperature in excess of 20°C although intermittent rises up to 35°C might occur.

A80. Other research has included tests with glass fibre reinforced polyester pipes, and these indicate that the loads on flexible pipes are probably less than those calculated by Spangler's theory. It was concluded that:

(a) the stress at the top of the pipe is a function of the rigidity of the pipe and the change in vertical diameter;

(b) the amount of compaction of the filling at the sides of the pipe reduces the deformation and moment;

(c) the vertical earth load is smaller than the weight of the column of earth over the pipe; and

(d) the stress in the pipe when laid in sand or gravel is small.

It is considered that by specifying a maximum allowable deformation the moments in the pipes can be controlled. The pipe thickness of the material should be determined by the need to avoid buckling.

A81. Other research has included an investigation of loads on rigid underground pipes by Janson. The investigation was initiated to follow up overseas research and to carry out practical tests. Janson pointed out that whilst the static load on pipes is the least of the loads calculated by the narrow trench theory, the embankment theory and the wide trench theory, the use of mechanical excavation has resulted in the embankment theory forming the basis of design. From soil box and full scale experiments recommendations for design loads on pipes were produced. The difficulties of co-relating soil box results with actual conditions and the high intensity of traffic loading were commented upon.

A82. A study of flexible pipes was carried out by Molin similar to the study by Janson on rigid pipes. Flexible pipes were defined as those pipes whose strength was independent of their stiffness and it follows that both the pipe and the surrounding earth fill must be taken into account in their design. The work included tests on buried pipes in the laboratory soil box and in the field with both vehicular traffic loads and high earth fill using glass fibre reinforced polyester and steel pipes. The results of the tests carried out with flexible pipes embedded in soil can be summarised as follows.

(a) The vertical load on the pipe due to the dead weight of the earth is less than the total over-burden pressure at pipe-crown level. Since the load depends upon the ratio of the vertical compression of the pipe and of the side fill, the degree of compaction of the side fill influences the load on the pipe.

(b) The magnitude of the deformation of the pipe is governed by the deformation characteristics of the side fill and these are best determined in the laboratory by compression tests in cylinder apparatus and in the field by soil pressure measurements.

(c) For pipes of low inherent rigidity it can be shown that ring moments are proportional to the pipe rigidity and deformation and it follows that ring moments can be controlled by specifying the permissible pipe deformations. Compaction of the side fill reduces pipe deformation and hence moments in ring section and the required amount of compaction can be estimated in the laboratory before construction by means of tests on the fill material. In the case of pipes of low rigidity or large diameter the stresses during construction can be considerably greater than those after backfilling and it may be economic to stiffen the pipe temporarily.

(d) Although ring moments govern pipe dimensions the risk of buckling is the critical factor for pipes of low rigidity.

(e) Variation in the load on the pipe causes variation of the pipe deformation. Since the pipe only partially resumes its original shape when the load is removed, repeated loading can lead to collapse. Therefore where traffic loads occur it is necessary to prescribe a minimum height of fill over the pipe crown to limit deformation and to impose special requirements for the composition and compaction of the side fill.

It was considered that tests on other pipes and further tests on buried pipes with internal pressure should be carried out to ascertain the measures to be taken when traffic loads occur. It was also concluded that the influence of uneven movements in the longitudinal direction should be studied.

A83. In view of the way the properties of plastics materials are affected by temperature the Swedish Plastics Association have sponsored an investigation of temperatures in drain pipes serving dwellinghouses. The maximum recorded temperature on the outside of the pvc pipe was 47°C but temperatures in excess of 40°C were relatively unusual. Tests have also been carried out with a washing machine simulator on the basis of normal discharges at 85°C to 90°C.

Switzerland

A84. Sewerage is normally designed in accordance with regulations and guidelines which have been recently extended to cover asbestos cement and plastics pipes.

A85. Concrete ovoid pipes with flat bases are used in sizes 400 × 600 mm to 1200 × 1800 mm; pipes above 700 × 1050 mm are reinforced. Concrete pipe sewers range from 250 mm diameter in 50 mm stages to 500 mm diameter and then in 100 mm stages to 1000 mm diameter. Pipes larger than 1000 mm diameter are reinforced. Ogee joints with a collar and spigot and socket joints with a single or double stepped socket are used. Whilst it is desirable that the cross section of a sewer should be as uniform as possible the Swiss standard for the manufacture of concrete pipes permits considerable tolerances in the dimensions.

A86. Pipes are liable to attack from acids. Whilst painting with impervious paints extends the life of concrete pipes, those made with special cement are considered resistant to normal attack. Clayware pipes are regarded as practically proof against chemical attack. Clayware pipes are also regarded as resistant to abrasion but 1% of concrete pipes are liable to damage if a poor profile and gradient are selected. On the other hand special concrete pipes conveying sewage with velocities over 8 m/s have not been damaged after 25 years use. Although clayware pipes are said to be dearer than concrete pipes the additional cost is thought to be small in Switzerland compared with the total cost of sewer construction.

A87. Minimum trench widths listed in *Regulations for the construction of trenches* depend on the diameter and depth of the pipe and are 400 to 700 mm wider than the pipe diameter. In poor ground conditions special supports have to be provided requiring the trench to be widened by 400 mm. Excavation below the top of the pipe should be by hand and have vertical walls. Frozen material should not be used for backfilling trenches. It is recommended that the cavities between pipes and the trench walls which appear when vertical supports are withdrawn should be filled with concrete.

A88. Concrete bedding 100 mm deep under the pipe, with various types of haunching and surround are used. Granular bedding with a depth of diameter/8 or a minimum of 50 mm under the pipe, carried up to meet a line through the centre of the pipe at 30° to the horizontal where it cuts the pipe face is also used, the pipe being covered with fine sand for a depth of 150 to 300 mm.

A89. Unreinforced concrete pipe depths range from 0·5 to 10 m for 100 mm diameter pipes in streets and from 2·6 m to 4 m for 1000 mm diameter pipes. To prevent interference with gas and water pipes, drains should be at least 1·5 m deep. As a result sewer inverts are normally 3 to 5 m below ground. Minimum gradients should give a minimum velocity of 0·60 m/s, or in the extreme 0·50 m/s, and a minimum depth of sewage of 20 mm.

A90. Pipes are tested for water-tightness after backfilling.

A91. Although houses in country areas have long connections to the sewers, the latter are not usually deeper than those in towns because of the deeper cellars in towns. Connections have a fall of 3% and the point of connections at least 500 mm below the cellar floor and at least ⅔ of the diameter of the sewer above its invert.

A92. Professor Horler in his book *Drainage* commented that Imhoff restricted the maximum sewage velocity to 2·5 m/s for normal concrete and 5 m/s for special concrete and clayware pipes. Horler however suggests that velocities of 8 to 10 m/s should be permitted for a full pipe with very steep gradients as the sewer would be three times cheaper than if backdrops were provided. The sewer would however have to be replaced in 30 to 50 years. Pipes are normally laid with flush soffits to correspond with the hydraulic gradient when the pipe is full. However, where gradients are flat, pipes are laid with level inverts to obtain a greater velocity in dry weather. Where there are breaks in the gradient at changes of diameter it is thought that the hydraulic gradient should determine the design and at a change from a flat gradient large pipe to a smaller steeper pipe a vertical drop may be used. In designing sewerage the need to take account of water, earth and wheel pressures and particularly the bedding are noted since uneven bedding can result in the destruction of a pipe. The upward pressure from underground water must be taken into account and an earth load of at least 1½ times the net upward pressure is recommended. It is regarded as important that pipes passing through areas which are the source of underground water supplies should be watertight but preferable to route sewers to avoid these areas.

A93. As hot water can damage pipes the maximum temperature of discharges is limited by regulations to 30°C. Large quantities of sewage above 30°C are cooled before discharge. Plastics pipes are being marketed to withstand continual temperatures of 85°C and maximum temperatures of 110°C in diameters of 40 to 70 mm. These are used to convey discharges from washing machines etc. Normal pvc sewers are said to withstand temperatures of 40°C in Switzerland.

A94. Manholes are provided at changes in cross section, gradient and direction, junctions of drains and at maximum spacings of 50 to 65 m for 500 mm diameter pipes, 50 m for 600 to 900 mm diameter pipes and every 80 to 100 m for 1000 to 1250 mm diameter pipes. Where pipes are over 1500 mm diameter, manholes are provided at a maximum spacing of 100 m or possibly farther apart. Manholes should be 1000 mm diameter or 900/1100 mm oval. Cast iron covers or possibly concrete covers with a steel frame should be 600 mm diameter. Perforated covers at end manholes and about every 200 m may be provided if they can be located to avoid smell nuisance. Large manholes in Zurich have 180 mm thick concrete walls and curved roofs. The cover is centrally over the pipe and the benching has a 1 in 10 gradient. Step irons should be every 300 mm and climbing recesses should be provided on the side of the sewer if the profile is wet. The benching height should be designed to suit the drain cleaning equipment.

A95. The City of Zurich specification for surface water drainage permits concrete, cast iron, steel, asbestos cement, pitch fibre and plastics pipes. Concrete pipes have to have socket and spigot or collar joints. Asbestos cement pipes should be frost resistant. The properties of plastics pipes are considered carefully and it is thought desirable that the strength of the pipes should not decrease with time.

A96. Voellmy's method of calculating the forces and stresses in pipes is applied to four types of bedding:

i. fine sand, diameter/8 or at least 50 mm under the pipe, and 150 to 300 mm above pipe;
ii. concrete bed up to 30° below pipe centre line;
iii. concrete partly surrounding pipe; and
iv. concrete surround (reinforced if required).

Beddings iii or iv are recommended in towns. Tables have been prepared indicating the appropriate bedding for a load of 6 tons for pipes from 100 mm to 1000 mm in diameter. The maximum depths for trenches and those for embankments or excavation by excavator are given for good or moderate ground. The maximum height of embankments and depths of excavation by excavator are lower than those for trench work for pipes 600 mm diameter and smaller.

A97. Wetzorke's method of calculating the earth load and traffic load related to the surface of the pipe is considered simpler than Voellmy's and is thought sufficiently accurate for most work. The influence of the pipe's dead weight and of the water pressure is neglected. The total load obtained from the earthload, the surface load and the traffic loads are compared with the ultimate load, the latter taking account of the bedding factors. The ultimate load is based on the following safety factors:

(a) pressure on highest point of pipe from surface loading allowing for lateral compression of infilling material—safety factor of 1·5 in good ground and 1·8 in bad ground; and
(b) pressure on highest point of pipe from traffic loading—safety factor of 1·5 with cover up to 1 m and 1·8 with cover over 1 m.

A98. Research tests carried out for the Swiss Association of Cement Products Producers have shown that for 600 mm diameter concrete pipes on a sandy bed with gravel backfill, minimum heights of 0·20 to 1·80 m are required according to whether compaction is with a light vibro-roller of 380 kg in weight or with 1000 kg ram, if stresses in the pipe of over 50 kgf/cm^2 are to be prevented in the pipe.

West Germany

A99. There are a large number of Deutsche Industrienormen (DIN) standards relating to the construction of pipes and channels but there are no regulations requiring that these widely used standards be followed.

A100. DIN standards specify circular concrete pipes, concrete pipes with a flat base and ovoid pipes with ogee joints. Circular pipes are normally used with diameters from 100 mm to 1400 mm having lengths of 1 m. The ovoid pipes range from 600 × 900 mm to 1200 × 1800 mm and are also 1 m long.

A101. Clayware pipes are specified in diameters from 100 mm to 1200 mm each pipe being 1 m long. There are 90°, 60°, 45° and 30° bends, double bends, T's, Y's, crosses and double Y's: $\frac{1}{4}$ circumference, $\frac{1}{2}$ circumference and flat plates are also covered.

A102. Pre-cast concrete manhole sections have a diameter of 1000 mm, a depth of 500 mm and taper eccentrically to a diameter of 625 mm, the taper section having a depth of 600 mm.

A103. Brick lined sewer blocks for ovoid sewers from 700 × 1050 mm to 1600 × 2400 mm are specified.

A104. Asbestos-cement pipes are specified in diameters from 150 mm to 1500 mm and in lengths from 4 to 5 m. 45° Y's and T's are only listed for pipes up to 350 mm diameter and 15°, 30° and 45° bends for pipes up to 300 mm diameter.

A105. The code of practice on sewerage construction gives detailed guidance on the construction of sewers. The usual bedding of circular pipes without a flat base has a bedding angle of 90°. Larger or smaller bedding angles, but not less than 60°, are permitted for concrete, reinforced concrete and clayware pipes provided suitable allowances are made in the calculations. The trench bed must not be loosened, driven on, or disturbed by spillage or freezing. Loosened cohesive soil must be replaced by non-cohesive material or a special pipe bed. In sandy soil and fine gravel, asbestos cement, cast iron, plastics and steel pipes of any diameter and concrete, reinforced concrete and clayware pipes up to 600 mm diameter may be laid on a levelled trench bed. Pipes may similarly be laid on cohesive soil if the soil is suitable. Direct laying on other soils, i.e. soils with coarse gravel and stones, firm soils and rock, is not permitted. Where the natural trench bottom is not suitable it is replaced with a layer of sand, fine gravel or concrete at least 100 mm plus $\frac{1}{10}$ of the nominal diameter of the pipe deep and the layer is compacted to the shape of the pipe with a 90° bedding angle for the full width of the trench. If there is a possibility of the bed spilling out through ground water drainage it is recommended that the pipe be laid on concrete with a minimum depth of 100 mm and at least 50 mm plus $\frac{1}{10}$ of the nominal diameter of the pipe. The concrete bed is shaped to give a 90° bedding angle and must be at least as wide as the pipe.

A106. The code indicates how the bearing capacity of a pipe may be increased by surrounding it or partially surrounding it with concrete. The surround is shown with a thickness of at least $\frac{1}{4}$ of the diameter of the pipe and a minimum thickness of 100 mm the top sloping upwards at an angle of 30°, and the partial surround rising to the crown of the pipe. Pipes must be flexible at connections to buildings and other structures. Pipes are tested before backfilling to a hydrostatic pressure of 5 m for a period of 15 minutes and deemed to be watertight if the added water does not exceed the quantities listed below.

(a) Concrete pipe lines

Size	Water in l/m^2 of wetted surface
100 to 250 mm diameter	0·40 (0·20 if reinforced)
300 to 600 mm diameter	0·30 (0·15 if reinforced)
700 to 1000 mm diameter	0·25 (0·13 if reinforced)
Over 1000 mm diameter	0·20 (1·10 if reinforced)
300 × 450 to 500 × 750 mm oval	0·30 (0·15 if reinforced)
600 × 900 to 800 × 1200 mm oval	0·25 (0·13 if reinforced)
900 × 1350 to 1200 × 1800 mm oval	0·20 (0·10 if reinforced).

The pipes should stand filled with water for 24 hours before the test.

(b) Clayware pipe lines

100 to 1500 mm diameter	0·20

The pipes must be kept for one hour in a filled condition under a hydrostatic pressure of 5 m before the test.

(c) Asbestos cement pipe lines

100 to 1000 mm diameter	0·20

The pipes must be kept for one hour in a filled condition under a hydrostatic pressure of 5 m before the test.

Backfilling has to be with stone free soil in layers up to 0·3 m thick to a height of 0·3 m over the pipe. Heavy tamping apparatus is not permitted until there is a cover of at least 1·0 m over the crown of the pipe. The need to differentiate in calculations between the trench condition and the embankment condition is stressed and the two are defined, the position of the crown of the pipe being the ruling factor. It is recommended that the impact and vibration factor be $1 + \frac{0\cdot3}{H}$ for road traffic loads and $1 + \frac{0\cdot6}{H}$ for rail and aircraft traffic loads where H is the cover over the pipe in metres. The depth of pipes should not be less than 0·5 m where laid under roads and 1·0 m where subject to rail or aircraft loads. Attention is drawn to the influence of the pipe trench dimensions on the distribution of the earth and traffic loads. Trenches more than 1·25 m deep must be lined. Vertical waling, horizontal waling planks between strutted supports and steel channel sheets are illustrated. The need to keep the trench bed free of water is pointed out and the use of a seepage conduit and a widened trench are suggested where necessary.

A107. Pipes of pvc are permitted and a draft standard for 100 to 200 mm diameter pipes has been published. Plastics pipes have been developed so that complete sections including shafts and connections can be assembled and lowered into a trench.

A108. Manholes are generally constructed at the head of sewers and at every change of direction, junction and change of section and step. They are usually spaced as follows:

pipe diameter	maximum spacing
up to 600 mm	up to 50 m apart
600 to 800 mm, or 600/900 mm	50 to 80 m
over 800 mm	80 to 100 m

On some old sewerage schemes manholes were spaced up to 160 m apart.

A109. In Munich sewers are normally constructed of clayware pipes with mechanical joints, concrete pipes being used only for the larger surface water sewers. Sewers from 200 mm to 350 mm diameter are laid in trenches about 1 m wide and surrounded with sand graded up to 7 mm. The sand has a depth of 50 mm below the pipe and 100 mm above the socket of the pipe. Clayware pipes from 400 mm to 600 mm diameter are bedded and haunched with concrete having a depth of 150 mm below the pipe. Sand up to 7 mm grading is placed on top of the pipe for a depth of 100 mm. Larger sewers are constructed of ovoid section in sizes from 1100 × 600 mm to 2600 × 2000 mm, and exceptionally 2800 × 2800 mm, using in-situ concrete. Some of the largest sewers have the greatest width below the mid point of the height of the sewer. They are lined with clay sections and the walls are rendered with a quartz sand mortar to resist abrasion or lined with clinker brickwork. Branches are required to enter the smaller ovoid sewers about half-way between the point of greatest width and the invert, although branches entering the largest sewers are at or slightly above the point of greatest width. Means of draining ground-water is sometimes provided under large sewers. Box culverts are constructed of reinforced concrete with a floor sloping to a semi-circular channel. In this city manholes are constructed at maximum spacings varying from 60 m to 175 m depending on the size of the sewer.

A110. A national standard gives guidance on placing pipes under public roads. The possibility of putting services into large ducts through which a man could walk is being investigated with the object of reducing the expense and inconvenience of work in roads. The practicability of installing sewers in these large ducts depends on local circumstances.

A111. Pre-cast sectional clayware ovoid sewers, surrounded with concrete, have been constructed. More recently the clay pipe industry has extended its range of pipes to include pipes 1·5 m long to reduce the number of joints. Pipe junctions have been developed and pipes with reinforced walls introduced to obviate the need for concrete surround. Reinforced concrete pipes are usually available in 5 m lengths. Non-reinforced concrete pipes are now available in 1·5 and 2·0 m lengths in addition to the traditional 1·0 m length. Non-reinforced pipes have been developed with a wall thickness such that they can be laid at cover depths up to 4·5 m without special measures. Concrete pipes with a flat base are frequently used as it is easier to make a flat bed than a rounded one. As a result of the need to accelerate work and produce watertight sewerage systems, reinforced concrete and asbestos cement pipes, usually with mechanical joints, are being used in greater quantities.

A112. Where sub-soil water is high and cannot be lowered without danger to the surrounding area, thixotropic fluids have been used to keep trenches open. Tunnelling from shafts is used to reduce delays from inclement weather, avoid disruption of traffic, reduce noise, and reduce disturbance of the surface and other services. Freezing has for some time been used as a means of stabilising subsoils for the construction of shafts and deep excavation. The technique is now being used for the construction of long lengths of sewer trenches. Very small pipes have been thrust or drawn under the surface. Plastics pipes have been particularly useful in these processes.

A113. Tunnel sewers are constructed of single or multiple ring masonry, prefabricated pipes, iron or reinforced concrete pipes, in-situ concrete tubes or by jacking steel or reinforced concrete tubing.

A114. Tests have been carried out to determine the effect of hot discharges from sinks and washing machines on plastics piping. It was found that the most unfavourable case for a fixed pipe subject to hot and cold discharges occurs when the duration of the hot discharge equals the duration of the cold discharge.

Middle East

Israel

(a) Generally

A115. The Ministry of Housing publish recommended street layouts showing the position of pipes and cables. A committee has been appointed to consider the principles and criteria for the design of sewerage systems. There are national standards for concrete and asbestos cement pipes; British and U.S.A. standards are also frequently used. It is thought that there is a fair degree of attention to standards and codes of practice as a result of licensing requirements and government supervision.

A116. Many old large sewers built of brickwork have failed as a result of the disintegration of mortar at the joints. It is reported that concrete sewers are now cheaper than brick sewers and are subject to less wear. Concrete sections include circular, egg-shaped, rectangular, semi-elliptical, horseshoe, oval and semi-circular roof with flat benching and semi-circular channels. The larger conduits are cast in-situ, usually in 2 or 3 stages, using steel or wooden moulds. Pre-cast concrete sections are used for tunnelling.

A117. Asbestos cement pipes are manufactured in diameters from 100 to 1500 mm and are connected with collar joints. Concrete pipes have spigot and socket, cement mortar or bitumen joints, or ogee joints with reinforced concrete collars or cement mortar surrounds. Concrete pipes are manufactured in diameters ranging from 100 mm to 1400 mm. Clay pipes are specified up to 500 mm diameter and cast iron pipes up to 1200 mm diameter. Steel pipes are used with butt joints, swaged joints or Johnson sleeve joints.

A118. Sewers are designed on the basis of the Marston theory, the advantages of using a narrow trench, particularly up to the top of the pipe, being appreciated. A safety factor of at least 1, based on the minimum ultimate breaking load, or between 1·2 and 1·5 based on the average breaking load is used. Types of bedding used are:

(a) concrete cradle—a concrete foundation at least 200 mm wider than the pipe, the bedding factor depending on the quality of the concrete and the length of the circumference of the pipe in contact with the concrete;

(b) concrete saddle—the pipe is laid on a granular foundation of crushed stone or gravel for half its depth, and the upper half covered with concrete or reinforced concrete to a depth of $\frac{1}{4}$ of the outside diameter;

(c) granular bed (type 1)—a bed of granular material at least 100 to 150 mm thick for a width of 60% of the external diameter on a shaped trench bottom;

(d) granular bed (type 2)—a bed of granular material $\frac{1}{4}$ × diameter thick under the pipe and extending halfway up the pipe;

(e) shaped trench bottom—trench bottom shaped to the profile of the pipe with a width of 50% of the external diameter of the pipe, the pipe being covered to a depth of 150 mm with granular material or material from the excavation free from lumps and stones.

In Israel type (d) is considered the most economical bedding. Pipes may be laid directly on the soil if it is firm and dry or on a levelled surface of sand or limestone. Laying on a trench bottom without shaping is not permitted. On soft or unstable soils such as mud, marshy soil or shifting sand, a thin layer of concrete is cast on to the soil or on to piles. Drains with open joints and covered with 100 mm of gravel or stone chippings are sometimes laid under conduits to remove water from the trench but these are abandoned when construction has been completed. Pipes are not laid on stone or hard soil. For high loadings concrete beds and possibly surrounds are used.

A119. Concrete sewers liable to carry industrial sewage or sewage with high sulphide content are lined with clayware segments and the joints are filled with acid resistant material. Pvc linings are used on some precast and cast in-situ concrete sewers. Steel or iron pipes may be lined with bitumen or cement mortar. Resin paints and sprays and vinyl paints are also used as acid resistants. Steel or iron pipes are protected from external corrosion by bitumen soaked asbestos, glass fibre, concrete, plastics or by cathodic protection. Special cements may be used for concrete or asbestos cement pipes, but special anti-corrosive measures are not normally required for clay pipes.

A120. Considerable attention is paid to the timbering of trenches.

A121. Manholes are constructed at the head of sewers, junctions and every change of direction, profile and diameter. On pipes up to 500 mm diameter, chambers are installed at maximum distances of 35 to 50 m although smaller spacings may be used for small sewers. For pipes which can be entered the distance is increased to 100 to 150 m. Manholes are usually circular with an internal diameter of 1 to 1·2 m. Manholes 0·8 m diameter are used for small shallow sewers. Rectangular chambers are a minimum of 0·8 × 1·0 m or 1·0 × 1·2 m for deep or large sewers. Channels are about $\frac{3}{4}$ of the depth of the sewer and benchings have slopes of 1:6 to 1:4. Care is taken to provide flexible joints in sewers near chamber walls. Manhole walls are constructed of in-situ concrete, prefabricated concrete, concrete blocks or bricks. Brick or block walls are at least 200 mm thick but cast in-situ walls may be thinner if reinforced. Pipes entering manholes with vertical drops are sometimes provided with rodding pipes extending to the surface; any blockages are cleared by a heavy ball and chain. Rodding eyes are constructed at the end of sewers provided the distance between the rodding eye and the nearest inspection chamber does not exceed 45 m. Manual or automatic flushing chambers, based on flows of 2 litres per person per day, are constructed where sewers are likely to be blocked by sediment.

A122. The construction of large diameter sewers in a long arc is sometimes allowed.

A123. Sewers are usually tested under a hydrostatic pressure of at least 1·2 m and not more than 6 m for 24 hours. The amount of water added should not exceed 30 l/km per hour per 25 mm of internal diameter for sewers up to 450 mm diameter. Pressure pipe lines are tested to comply with a maximum leakage of approximately 23 l/km per hour per 25 mm diameter at the working pressure.

A124. The Ministry of Health state that sewer pipes should be at least a metre horizontally from water mains and the sewer should be at least 300 mm below the water main. Where the water mains and sewers cross, there should be at least 1 m in a vertical direction between the pipes. Where it is not possible to comply with these two requirements the sewer should be constructed of cast iron, covered with at least 150 mm of concrete and a sleeve pipe installed. Sleeve pipes are also used for shallow sewers under roads.

A125. The Swedish pressurised sewerage system using plastics pipes has been used to sewer a large number of houses in Carmel.

(b) Tel Aviv

A126. The Municipality of Tel Aviv uses asbestos cement pipes 2 to 2½ m long for sewers 100, 150 and 200 mm diameter and 4 to 5 m long for larger sizes up to 1500 mm diameter. Pipes are jointed with rubber rings. They are capable of withstanding a 3 edge bearing load varying from 3000 kgf/m run for 100 mm diameter pipes to 13,000 kgf/m run for 1500 mm diameter pipes. Sewers normally have a minimum diameter of 150 mm and connections a minimum diameter of 100, 150 or 200 mm. In addition to asbestos cement pipes, pipes of concrete or reinforced concrete are used. Plain concrete pipes are used by small communities for stormwater drains.

A127. Pipes are laid on sand, 100 to 200 mm thick, carried up to the top of the pipe. Trenches are constructed with vertical walls and of minimum width. Sewers are not pressure tested. Sewers with less than 1 m of cover are protected by reinforced concrete and those with more than 3 m of cover are strengthened with concrete surround or constructed with special pipes.

A128. In-situ reinforced concrete manholes 1 m diameter are constructed for sewers up to 1000 mm diameter. Manholes for larger pipes are constructed square or pentagonal in shape with bricks or reinforced concrete. Manhole openings are 0·5 m diameter. Cast iron step irons are placed at 350 mm spacing in shallow manholes and ladders and platforms are constructed in deeper manholes.

A129. Sewers are ventilated through house connections. Sewage from low lying buildings is pumped by private pumps so that the Municipality are not responsible in the event of any sewage flowing back from the sewer to private premises.

Australasia

Australia

A130. Responsibility for design rests mainly with the State Governments or Statutory Corporations set up by the State Governments.

A131. There are national standards for concrete pipes, vitrified clay pipes and rubber ring joints for vitrified clay pipes. There are also codes of practice for the construction of clay pipe and concrete pipe sewers. Generally clay pipes are used up to 24 in diameter and reinforced concrete pipes are used for larger pipes. A limited number of small asbestos cement pipes are used. The 1962 code of practice for concrete pipes details methods of evaluating loads on buried pipelines based on Marston's formula.

A132. The 1968 code of practice for the construction of vitrified clay pipelines includes a pipe design section based on a consideration of beam loading forces and shearing forces acting on small diameter pipelines. It was concluded that for 4 in and 6 in diameter pipes the strength when acting as beams was the controlling factor but that the importance of ring loading strength tended to merge with beam loading strength before the diameter reached 9 in. Load factors which take account of the type of bedding are not applied to estimated beam loadings. All pipes are designed for ring loading and 4 in and 6 in diameter pipes are designed for beam loading as well. Tables indicate the allowable load in lbf/ft run for properly laid pipes but these loads are reduced to $\frac{1}{3}$ if there is any possibility of the sockets resting on the sub-grade. Bedding load factors are calculated on the basis that the mortar and concrete have obtained a strength of 2000 lbf/in^2 and that the beddings have been allowed to cure for 28 days before loads are applied. Account has to be taken of uneven hardness of the ground, uneven bedding, swelling and shrinkage of the ground, relative movement between a building and a pipeline, subsidence due to mining, changes due to ageing of the pipe, non uniformity due to methods of construction and superimposed loads such as wheel loads. Whilst trench widths have to provide at least 3 in on each side of the pipe they are kept as narrow as possible. Timbering, sheeting and tunnelling have to be carried out in accordance with statutory regulations. A test for soft areas and means of stabilising unstable ground are specified.

A133. The code of practice lists methods of pipe laying and mentions the need to prevent washout of bedding on grades over 3%. Concrete cradles are interrupted at each socket; they support at least the bottom quadrant of the pipe and are at least 8 in wider than the pipe. Concrete surround is at least 4 in thick. With rigid joints a minimum gap of $\frac{1}{8}$ in is left between the face of the socket and the spigot to allow for expansion of the pipe barrel.

A134. Manholes are constructed at all branches, bends, change of grade and every 400 ft on straight runs. Flexible joints are provided on each side of a manhole, short lengths of flexibly jointed pipes being used to join sewers to the flexible joint near the manhole. Junctions are bedded, encased or covered with concrete and have a short length of flexibly jointed pipe on either side. Vertical and sloping connections must not transfer loads to a sewer.

A135. Trenches are backfilled in 6 in layers of selected material to a height of 12 in above the pipes. Backfilling may be consolidated by flooding. Pipes are tested by water to a hydrostatic head averaging 10 ft and the leakage is not to exceed $\frac{1}{2}$ gallon per inch of diameter per 100 ft per hour.

A136. The Melbourne and Metropolitan Board of Works use vitrified clay pipes for 4 in, 6 in and 9 in diameter sewers or cast iron pipes where the ground is poor. For sewers from 12 in to 24 in diameter vitrified clay pipes are frequently used, although less expensive concrete pipes are used where the risk of corrosion is slight. Reinforced concrete pipes are used for all larger sizes of sewer. Neoprene joint rings are used if suitable pipes can be obtained but some 12 in, 15 in, 18 in and 21 in diameter vitrified clay pipes do not meet the tolerances required for rubber ring jointing and these and all 24 in diameter clay pipes are cement mortar jointed. Cast iron pipes have bolted glands and all concrete pipes have neoprene ring joints. Polyurethane and pvc joints for clay pipes are not considered capable of standing joint pressures for a sufficient period.

A137. Pipes are laid and haunched with not less than 3 in of fine crushed rock bedding, the bedding being carefully compacted around the pipe except where it is removed for the socket. As part of the factory acceptance testing, ring loading tests are performed on pipe samples of all diameters and beam loading tests on 4 in and 6 in diameter pipes. In the construction of sewers of 18 in diameter or less, additional flexibility is given to the pipeline at manholes and other discontinuities by arranging for flexible joints and 2 ft long pipes adjacent thereto. The Board do not consider pvc and polythene pipes have sufficient durability or economy to justify their use in permanent sewer installations.

A138. Experiments have been conducted to measure the beam loads and joint shear loads to which mechanically jointed 4 in diameter vitrified clay pipes were subjected under a variety of soil loading and bedding conditions. A similar investigation is to be made into the bedding of 9 in diameter mechanically jointed pipes. The 4 in diameter pipe tests have shown that where a high standard of bedding, consisting of well crushed rock, is used and the socket is relieved from any direct action on the sub-grade or bedding, joint shear loads up to 100 lbf may occur. Where the bedding is below standard shear loadings of 400 lbf are probable and loadings of 600 lbf are possible. A heavy truck over a 4 ft long pipe 18 in deep can produce a distributed beam load of 2000 lbf if a high standard of bedding is not produced. Beam and shear loadings to which pipes laid in tunnel excavations are subjected are slightly less than those to which pipes laid in open trench conditions are subjected. Where a pipe is rigidly supported off the subgrade on only one side of a joint the total joint shear is approximately twice the load which might otherwise be expected. When the basic design criteria were revised to take account of these results the spigot and socket tolerances were so limited that the cost of production increased considerably. It was accordingly decided to relax the design criteria so that no joint between straight pipes would open under a shear load of 200 lbf (instead of 400 lbf) and no joint between fittings would open under a shear load of 100 lbf (instead of 200 lbf). As a result both the minimum spigot outside diameter was decreased and the maximum socket inside diameter was increased by 0·040 in. It is considered that there is a probability of 1 in 500 that a defective joint might be made and that the compromise between the cost of producing pipes to tight tolerances and the cost of infiltration and root entry is reasonable. The same joint design has been adopted by the Standards Association of Australia for vitrified clay pipe lines.

A139. The Metropolitan Water Supply Sewerage and Drainage Board of West Perth require sewers to have a minimum cover of 2 ft 6 in if not subject to vehicular traffic and 3 ft if located in the roadway. Drop manholes are used if the difference in invert levels exceeds 1·49 ft. Sewers are constructed with the following minimum gradients and trench widths:

diameter of sewer	min gradient	trench width
6 in	1/150	2 ft 9 in
9 in	1/200	2 ft 9 in
12 in	1/300	3 ft 0 in
15 in	1/400	3 ft 6 in
18 in	1/500	4 ft 0 in
21 in	1/650	4 ft 3 in
24 in	1/800	4 ft 6 in
27 in	1/1000	4 ft 9 in
30 in	1/1200	5 ft 3 in

House connections 30 to 150 ft long, are constructed at a gradient of 1 in 60.

A140. Vitrified clay pipes are used for 4 in to 24 in diameter sewers. Four inch diameter and 6 in diameter asbestos cement pipes are permitted provided:

(a) drop manholes are not used immediately below or anywhere above asbestos cement sewers;

(b) pumped sewage is not discharged through asbestos cement mains;

(c) pipes are not greater than 6 ft 6 in long and are jointed with neoprene rings; and

(d) they are not deeper than 12 ft.

Twenty-four inch up to 78 in diameter sewers are constructed of reinforced concrete plastics lined pipes to Australia Standard A35—1957, the plastics lining usually extending over an arc of 330°. Below the water table and in built-up ground sewers are supported on piles and bearers. In wet clay areas and built-up ground sewers may be supported on a concrete raft 3 in deep, 1 ft wide and a sand bed, the sewer being surrounded with a minimum of 6 in of sand. Pile and bearer supports or concrete surround are provided at road crossings if other services necessitate this. Sewers steeper than 1 in 25 have anchor blocks at a spacing in feet of twice the denominator of the gradient. Sewers constructed near a dividing boundary between separate building lots are encased in 6 in of concrete.

A141. Manholes are usually constructed of brick, precast concrete or in-situ concrete. Generally concrete manholes are only used where asbestos cement pipes are acceptable but concrete manholes lined internally with a plastics lining are used for sewers with a minimum diameter of 36 in. Manhole spacing does not exceed 300 ft for 6, 9 and 12 in diameter sewers, 400 ft for 15 in diameter sewers, 500 ft for 18 in diameter sewers and 600 ft for 21 in diameter sewers. Manholes are provided at all changes of direction and gradient.

A142. The Board are evaluating the performance of Type 50 high density polythene by laying lengths of 6 in, 12 in and 15 in diameter sewers.

A143. The Metropolitan Water, Sewerage and Drainage Board of Sydney point out in their instructions that in undeveloped country it is possible to have the advantages of open cut excavation and trench type loading by excavating down to 2 ft above the pipe with sloping sides and continuing with normal excavation. Care is taken not to exceed specified trench widths at the top of pipes but if this is unavoidable the bedding design is reconsidered. Granular bedding consisting of ¾ to $\frac{3}{16}$ in crushed stone with a minimum depth of 4 in in earth and 6 in in rock, the latter depth being maintained under the socket, is frequently used for vitrified clay pipes. Alternatively, a concrete cradle bedding at least 8 in wider than the pipe diameter and with a minimum depth of 4 in for pipes up to 16 in diameter and 6 in for pipes 18 in diameter and over is used. Concrete encasement is used on steep grades to prevent erosion of the bedding or where other methods are considered inadequate. Surround and cradles are interrupted at the face of each socket by a ½ in thick membrane. In very soft ground piles are used or the soft strata replaced with graded material. Pipes may also be bedded on local material, on 2 in of imported sand, on 1:4 cement mortar 2 in thick, on concrete or may be supported on timber piles. Wedges under pipes are forbidden. Well graded ¾ to $\frac{3}{16}$ in crushed stone is considered a better bedding than a uniformly graded material of ½ in stone, but the latter is preferred to well graded round pea gravel. An angular material is considered more stable and more suitable than a rounded material of similar grading, the stability of both increasing as the size of the particles increases.

A144. Pipes are laid with a minimum cover of 4 ft 6 in under roads and 3 ft under footpaths. The Board use:

(a) vitrified clay socket and spigot pipes, 2 to 6 ft long, with rubber ring joints, polyester rubber ring joints or polyurethane joints;
(b) concrete socket and spigot pipes, 8 to 12 ft long, with rubber ring joints or concrete ogee joint pipes 8 to 20 ft long; and
(c) cast iron socket and spigot pipes, 12 to 18 ft long or flanged pipes up to 17 ft 6 in long.

The upper end of a steep gradient, where the sewer is designed to capacity, is the same diameter as the incoming pipe for at least 20 ft and a manhole is inserted at the change of diameter or the larger size pipe continued to the next manhole.

A145. Manholes are normally constructed of in-situ or precast concrete but trials are being made of manholes with fibreglass and asbestos cement walls. Manholes are located at the head of sewers, junctions, changes of diameter, direction and gradient. They are spaced as follows:

diameter of pipe	spacing
12 in	400 ft
15 in to 30 in (velocity less than 2·5 ft/s)	400 ft
15 in to 30 in (velocity more than 2·5 ft/s)	500 ft
36 in to 42 in (sewers)	500 ft
48 in (trench)	500 to 1000 ft
36 in (tunnel)	750 ft
42 in to 66 in (tunnel)	1000 ft

The change of direction of a 24 in or 30 in diameter sewer is restricted to a maximum of 20° through a standard manhole, greater changes of direction being made with curves having a minimum radius of 50 ft. A manhole is normally placed a suitable distance from the upstream tangent of the curve. The change of direction of 36 in diameter or larger sewers at manholes is not allowed to exceed 10°. The Board build manholes with concrete rings, straight or conical, for sewers up to 30 in diameter. The chambers of deep manholes may have a flat or semi-circular roof. Sewers are surrounded with concrete where the cover is less than 2 ft; where they cross under a watercourse other than in a cast iron pipe; where they pass under a structure; or where they are placed in the invert of a stormwater channel. Joints are protected with concrete where the sewers are near fibrous roots. Ventilation shafts are spaced not more than 1000 ft apart and are based on average air changes of 2 per hour and a wind velocity of 8 miles per hour. Shafts should have a diameter of about ½ the diameter of the sewer subject to a maximum of 12 in. Six inch diameter clay pipe lamp holes may be used in place of manholes for 6, 9 and 12 in diameter clay pipes if the sewer is self cleansing and there is only one inlet and one outlet. The lamp holes must be not more than 300 ft from a standard type manhole on sewers not more than 5 ft deep to invert and not more than 200 ft from a standard type manhole on sewers more than 5 ft but not more than 7 ft deep. Large diameter concrete pipes may be laid on curves of 50 ft radius by pulling the joints up to 9½° and surrounding them with reinforced concrete.

A146. Trenches are normally backfilled with selected fine material up to 3 in above the top of the pipe and approved material from the trench for the next 9 in. For clay pipes this initial backfilling is with 12 in of fine material lightly consolidated.

A147. In Sydney pipes are designed to carry 4 times dry weather flow for densities of 30 persons per acre, falling to twice dry weather flow for 80 persons per acre. Gravity sewers may be designed to carry a reduced rate of 2½ times dry weather flow in addition to 1·3 times the sum of the pumping rates where there is a large volume of trade waste from one or more sources. The factor of 1·3 is intended to cover the increased pumping rates from flood levels in the pump wells. Tunnel sections and sections where capacity is available above the normal sewage level may be designed for 3 times the dry weather flow for densities up to 30 persons per acre. Designs are based on 4·3 persons per dwelling and a dry weather flow of 60 gallons per head per day. Structural design is based on the U.S.A. Water Pollution Control Federation Manual of Practice No 9 *Design and Construction of Sanitary and Storm Sewers 1969.*

A148. A committee has been studying hydrogen sulphide and sulphuric acid attack on sewers using a sulphide corrosion test chamber. Tests of the root penetration past rubber rings have been carried out using chemical inhibitors. Fibreglass overflows, vortex drops, brick linings of large sewers, plastics linings of pipes and stainless steel vent shafts are being tried out in service. Upward curved pipes with surface boxes are being tried out to see if they can be used to replace manholes at deadends. The University of New South Wales has carried out research into the growth of algae in sewage.

New Zealand

A149. Standards for sewer construction are not uniform throughout the country. The urban areas have their own standards and much of the work in the country areas is based on the New Zealand Ministry of Works Design Manual for Water Supply and Sewerage.

A150. There is a New Zealand Standard Specification for *Ceramic* (*Earthenware*) *Sewer Pipes* covering pipes from 4 in to 15 in diameter with mechanical joints. Pipes are required to be at least 2 ft and not more than 5 ft long. The pipes have to stand a 3 edge bearing crushing load of 2250 lbf/ft without cracking. The specification dated 1967 covers glazed, unglazed or partly glazed pipes and includes an appendix specifying tests of joints. The joints have to permit a deflection of ½ in per ft length of pipe without visible leakage when subjected to a hydrostatic pressure of 10 ft.

A151. There are also New Zealand standards for reinforced concrete and asbestos cement pipes. New Zealand Standard No 7 of 1965, based on Australian Standard CA 33 of 1962, covers *Concrete pipe laying design*. The standard for concrete pipes covers pipes from 4 to 72 in diameter and the pipes have to comply with an absorption test of 8%; or 6·5% if specially ordered for the conveyance of sewage or for pressure pipes.

A152. In 1967 a committee set up to draft a code of practice for the construction of sewers sent a questionnaire to many large drainage and sewerage authorities and obtained the following information from the fifty replies:

Two-thirds of the authorities issued standard specifications for the construction of sewers. Glazed clay pipes with rubber joint rings were most frequently used for house drains. Asbestos cement and, to a limited extend, concrete pipes were used for some house drains. Neoprene sleeve joints were also used. Sixteen out of forty authorities did not permit cement mortar joints for house drains. Concrete and asbestos cement pipes with rubber ring joints were widely used for sewers. Half the authorities did not permit cement mortar joints for sewers. New Zealand standards for pipes and joint rings were normally followed. Most authorities inspected but did not test pipes on site. Two-thirds of the authorities did not specify a maximum trench width but unsuitable trench foundations were usually replaced with granular material or weak concrete. The most frequent form of bedding of house drains was to lay these on the trench bottom and the next most frequent choice was granular bedding. The use of structural concrete was confined to peat soils. The most common form of sewer bedding was to bed the pipes on granular material but direct bedding, granular surround and weak concrete haunch were all used. The minimum depth of granular bedding varied from 2 to 12 in; some authorities used a depth of half the pipe diameter. Many authorities broke the continuity of the concrete bed at pipe joints. There were wide variations in the minimum cover over sewers and some authorities protected sewers with concrete cover slabs. Most authorities made provision for future connections by installing sealed branches opposite building frontages but some preferred saddles. Manholes were usually provided at changes of grade or direction, at junctions and at changes of diameter. Only two-thirds of the authorities required manholes at the head of sewers. The minimum spacing of manholes varied from 100 ft to 400 ft with an average of 308 ft. About one in three authorities permitted lampholes at the head of sewers. Circular manholes were preferred to rectangular manholes. The minimum diameter of circular manholes was 36 in and the average diameter 42 in. The mean size of rectangular manholes was 42 × 36 in. Testing procedure varied but there was a preference for testing house drains before backfilling. Test head varied from 2 ft to 10 ft and the time allowed for absorption from 15 minutes to 26 hours, averaging 15 hours for concrete and asbestos cement pipes and 12 hours for glazed clay pipes. The duration of test varied from 15 seconds to one hour and there was a wide variation in the amount of exfiltration premitted. Air tests were usually permitted where a water test was impracticable. Trenches were backfilled for 6 to 12 in above the pipe with fine material and above this with selected material. There was a preference for the initial layer to be hand tamped.

A153. The Auckland Regional Authority issue drainlayer licences. They require pipes, with a cover of 18 in or less in residential property, or 3 ft or less in other property, to be encased in concrete. Connections are by Y junctions unless the sewer is 12 in diameter or over. New drains have to be constructed on the separate system or so that they can be separated at a later date if they are temporarily connected to a combined system. Leakage is not to exceed one gallon per hour per inch of diameter per 1000 ft of sewer. The widths of trenches are limited to 2 ft 6 in for pipes up to 14 in diameter, and external diameter plus 15 in for pipes over 14 in diameter and not exceeding 27 in diameter. Beddings used include sand, concrete, concrete surround and concrete saddle with sand bedding. Precast manhole sections are clamped together with galvanized rods, pin joints or bolted joints and joints set with cement mortar. All pipes entering manholes have a flexible joint within 3 ft of the manhole wall. Curves on sewers are permitted within the limitations of the joint.

A154. The Ministry of Works have developed tables dealing with loading on pipe sewers and pipe strengths. The various types of pipe are grouped into 'pipe strength groups'. Design according to the tables allows for a minimum safety factory of 1·5 against cracking if the pipe cracking strength is at the bottom of a group, or 2·0 if the cracking strength is at the top of the group. There are tables for different trench widths and various beddings are taken into account. The simplified tables may result in conservative designs for pipes at the tops of groups.

A155. In the City of Auckland trenches are backfilled using selected earth filling for a depth of 12 in over the pipes and around manholes. The remaining backfill is carried up in layers not exceeding 6 in deep in streets or 9 in elsewhere. Two men ramming are employed for each man filling. All pipes are cradled on concrete bedding using 8:1 or 5:1 concrete depending on the ground. In bad ground 5:1 reinforced concrete bedding is used. All bedding and haunching is broken at the pipe joints by a strip of softboard. In wet trenches the concrete bed is supported along each side by timber kerbs to provide drainage channels at least 3 in deep. The top of the bedding normally slopes away from the pipe at 30° to the horizontal. Bedding and surround are at least 4 in thick for 6 in and 9 in pipes, 5 in thick for 12 in and 15 in pipes and 6 in thick for 18 in, 21 in and 24 in diameter pipes. Bedding may be omitted for asbestos cement pipes with turned ends and rubber ring joints. Sewers are encased in concrete a minimum of 6 in thick in streets or street reserves where the cover is less than 4 ft or the outside diameter of the pipes whichever is the greater, in private property where the cover is less than 3 ft or where the cover is less than 6 ft under a building.

A156. Curves are permitted on large stormwater sewers provided a man or obstruction would be visible from either of two adjoining manholes and these are not more than 300 ft apart. Manholes are required at the head of all sewers although a lamphole may be permitted where the end section does not exceed 100 ft in length. They are normally built of 5:1 in-situ concrete, the invert and channels being formed with half pipes or, exceptionally, concrete. Manhole walls are 6 in thick, or 9 in thick where wheeled loads are possible, and the internal diameter of manholes is 3 ft 6 in. Benching has a slope of 1 in 12. Manholes must withstand a leakage test of not more than one gallon in 24 hours. Precast concrete manholes are also allowed. Junction pipes are inserted in sewers less than 12 in diameter and embedded in concrete 4 in thick up to the midheight of the junction pipe. On pipes 12 in diameter and over pipes are saddled. Junctions are usually made at 45° to the vertical or to the flow, the branches having 4 in thick concrete cradle support. Sewers tested with water are subjected to a hydrostatic pressure of 3 ft over the soffit of the pipe at the upstream end and not more than 8 ft at the downstream end. The leakage must not exceed 3 gallons per 1000 ft of pipe per foot diameter over a test period of 15 minutes. Alternatively an air test with a pressure equivalent to 12 in of water may be applied. The pressure must not fall lower than 10 in of water over a 5 minute period. A smoke test under a pressure equal to 4 in of water is sometimes applied. In addition to the above tests an infiltration test may be applied. The maximum amount of infiltration must not exceed 60 gallons in 24 hours per inch diameter of pipe, per mile of sewer.

A157. Sewers are designed to comply with the following minimum gradients:

diameter	6″	9″	12″	15″	18″	21″	24″
stormwater		1/190	1/280	1/380	1/480	1/590	1/710
foul sewage	1/180	1/300	1/450	1/600	1/750	1/950	1/1150

These are based on velocities of 2½ ft/s for stormwater sewers and 2 ft/s for foul sewers when flowing half full.

A158. Rising mains are usually constructed of asbestos-cement pressure pipes with rubber ring joints but polythene, copper, cast iron, reinforced concrete or concrete lined steel pipes may be used. Pipes are bedded in the same manner as sewers. Rising mains are subjected to a hydrostatic test of at least 80 lbf/in^2 at the high end. Chambers are provided, not more than 270 ft apart, at any change of direction and to provide means of draining the rising main. A removable section 2 ft long is incorporated in these chambers. Thrust blocks are provided where required.

A159. Research is being carried out to determine realistic design criteria relating to quantities of sewage and allowable infiltration for different types of building in different areas.

A160. Large pipes in Dunedin are designed in accordance with Australian Standard CA33, which is based on Spangler's investigations. Other papers based on Marston's theory are used as a basis for design.

A161. Beach sand is cheap in Dunedin and most aggregates are of crushed quarry stone. Much of the area is below the highest tide level and in this area the standard method of laying is on a 4 in layer of 2 in all-in graded base supporting 1⅝ in paving slabs under the pipe collars with flooded and vibrated sand bedding and sand back-filling. In the silty-clay hill areas excavated material is used for backfilling and a concrete bedding and haunching with or without reinforcement is used to resist undermining as sub-soil water tends to follow the trench. Concrete haunching reduces the quantity of material to be handled in this difficult terrain. Large pipes are constructed on a concrete base and subsequently haunched. Whilst minimum trench widths are specified it is also stipulated that trench widths should be kept as small as possible. Rubber ring joints or mortar joints with 1:2 cement mortar are permitted. The engineer may require a jack to be applied to cement mortar joints to ensure that pipes are driven home when joints are required to be flexible, unreinforced haunching should be broken at intervals by softboard.

A162. Manholes have a 9 in base slab, 3 ft by 3 ft internal section and 6 in top slab. Wall thicknesses vary from 8 in when in roadways to 6 in when in grassed areas and footways where pipes are less than 6 ft deep. The channel is formed for the full height of the pipe. Flexible joints are constructed within 2 ft of manhole walls and the haunching broken. Pipes are tested to withstand a hydrostatic pressure of 10 ft before haunching. Backfilling up to 9 in above the pipe barrel is by hand with selected material free from stones for clayware and asbestos cement pipes, and free from stones larger than 2 in for concrete pipes. It is rammed in 12 in layers by hand. Above this level backfilling is in 6 in layers rammed by mechanical rammer. Sand backfilling is consolidated by flooding and vibrating.

A163. Clay pipes manufactured by the Amalgamated Brick and Pipe Company of New Zealand are graded on the basis of their maximum and minimum dimensions. In addition their departure from circularity must not exceed 0·1 in. The company stress the effectiveness of good bedding but consider that in extreme cases it may be necessary to encase the pipes with a concrete arch.

North America

Canada

A164. The provinces, and to some extent the cities, are autonomous in many respects and some have a close link with America and rely on American standards. The Canadian Government Specifications Board have issued specifications for pipes including asbestos cement and pitch fibre pipes. With responsibility divided between so many bodies, wide variations in requirements are understandable. The following notes should therefore be regarded as a general impression based on information from a limited number of towns.

A165. Vitrified clay pipes, varying in diameter from 4 to 12 in with 2 in increments, are used. A minimum size of 8 in for sewers is adopted in one area. Reinforced concrete pipes are used for the larger sizes of pipes. Excavation by narrow timbered trench or open battered trench is permitted. The maximum width of timbered trenches is specified, one authority limiting it to 4 ft plus the diameter of the pipe. Adjustments to pipe level must be by shovelling granular material or other filling under the pipe body. Manholes are normally located at the head of sewers, junctions, changes of diameter, direction and gradient. Some authorities allow a slight change of direction without manholes on very large sewers.

A166. In the city of Saskatoon pipes are bedded on a tamped layer of sand, at least 3 in thick, and sand is provided up to the pipe springing. The trench may be filled with granular fill passing a 2½ in sieve. Manholes are constructed of 42 in diameter reinforced concrete rings with tapered brickwork.

A167. In Vancouver there has been a long standing practice to bed pipes on concrete. Granular backfill in 6 in layers is placed up to 2 ft above the pipe. Manholes may be precast or monolithic construction. In-situ manholes are built of 1:5:4 concrete. Connections at 45° to the vertical or a vertical drop close to the sewer are permitted. Pipes less than 4 ft deep are surrounded in concrete. The city has a standard arrangement of a foul sewer constructed below a storm sewer and slightly off centre. The difference in level between inverts for an 8 in diameter foul sewer varies from 14½ in to 16½ in depending on the diameter of the surface water sewer. House drains have to be a minimum of 5 ft deep, except where they discharge to a septic tank. The maximum width of trench for house drains is 12 in wider than the pipe. Pipes are required to have a solid bedding; 4 in of gravel being used if necessary. Pipes on filled or made ground are of cast iron or supported on 3 in × 12 in × 8 ft long planks.

A168. In the province of Saskatchewan frost penetration may extend to a depth of 8 to 9 ft and sewers are normally laid at a minimum depth of 8 ft to avoid damage from frost. As a result of this and the flat terrain, the majority of sewers are at depths in excess of 10 ft. Separate sewerage systems are normal. Manhole spacing does not exceed 300 ft in small systems, 400 ft in larger systems and 500 ft in an outfall or storm sewer.

United States

A169. Clay pipes, mostly unglazed, are manufactured in diameters from 4 to 48 in and in lengths up to 5 ft. Although the American Society for Testing and Materials (ASTM) specification refers to standard strength and extra strength pipes, comparable with BS65, many manufacturers produce only extra strength pipes. Standardising production enabled the prices of the latter to be reduced so that it was no longer worthwhile producing standard strength pipes. Reinforced concrete pipes are available from 12 in diameter upwards. Unreinforced pipes are rarely used for sewer construction but may be used for local highway drainage. Reinforced pipes are manufactured in 5 strength classes to the sizes laid down in an ASTM specification. Pipes of a specific strength or intermediate size can be obtained. Concrete pipes are usually 6 to 8 ft long but are available in lengths up to about 16 ft. Limestone and dolomite aggregate are used in the south where hydrogen sulphide attack may be expected but such pipes are not available in other parts of the country. Cast in-situ concrete pipes are used to a limited extent for surface water sewers. Asbestos cement pipes up to 30 in diameter are used where sulphide attack is not prevalent. Corrugated steel pipes are used to a limited extent for surface water culverts; asphalt lined steel pipes are being produced for foul sewers. Pitch fibre pipes are rarely used. Glass fibre reinforced polyester pipes are being used in southern California and parts of the southern States.

A170. Where there is a risk of hydrogen sulphide attack on sewers due to high temperatures and long detention periods, concrete pipes are frequently lined and coated. Asbestos cement pipes may also be lined and coated. T-lock pvc lining, held in place by T-shaped keys, is widely used. Linings keyed to the pipe with epoxy resin or painted on are less popular. Asbestos cement pipes with a plastic resin coating are manufactured to combat sulphide attack.

A171. Unlined concrete pipes are usually cheapest from 12 in diameter upwards but if they have to be lined they are not competitive below 24 in diameter. Clay pipes are extensively used up to 18 in diameter but between 18 and 30 in diameter there is strong competition between clay, concrete and asbestos cement. From 30 in diameter upwards concrete is extensively used although corrugated steel, and clay up to 48 in diameter, may be used. Mechanical joints are normally used although some surface water sewers are jointed with a cement mortar bandage type joint. Cement mortar and bituminous joints are still used on some private drains.

A172. Although many manholes are constructed of brickwork there is a trend towards precast concrete. Thick-walled sections with rubber gasket joints but without concrete surround are sometimes used. Manholes on sewers under 36 in diameter are usually spaced at maximum spacings of 300 to 400 ft apart but in one area manholes are spaced at maximum spacings from 900 to 1200 ft on 6 in to 12 in diameter sewers increasing to 1500 ft on sewers above 24 in diameter. It is not uncommon for sewers to be laid on horizontal or vertical curves, short bevel pipes being manufactured to allow pipes to be laid on curves down to 60 ft radius. Y-branches are used to provide for future connections to clay and asbestos cement pipes. 90° junctions with short T-sockets and concrete pipes with knockouts are sometimes provided for future connections.

A173. Nearly all excavation is carried out by machine. Battered trenches are extensively used, sometimes in conjunction with protective shields or boxes which are moved along the trench and inside which the actual pipelaying is carried out. Close timbering is seldom used for vertical sided trenches. Granular bedding is normally specified but its grading and placing are not always closely controlled. Continuous concrete bedding is used in special circumstances. It is carried up the pipe for ¼ of the diameter for the full width of the trench. In New York all sewers are laid on a concrete bed. Concrete arch protection is sometimes used in place of concrete bed but concrete surround is rare due to its high cost. Surface water sewers and sometimes foul sewers are laid on the natural trench bottom although for foul sewers this is usually limited to locations where the soil is granular. In some areas jetting is used to assist consolidation. Mechanical compaction is only used where it is considered essential, i.e. under roads, and density tests are normally made to control its effectiveness.

A174. Infiltration tests are preferred to smoke and exfiltration tests. Infiltration requirements vary between 250 and 500 gallons per inch of diameter per mile per day.

A175. The following information relates to design in Los Angeles:

The city has a separate system of sewers, varying from 6 in diameter to 10 ft 5 in by 12 ft 3 in discharging to a 5 mile long outfall, 12 ft diameter. Sewers are normally located in the centre of streets with a water main on one side and a gas main on the other. For the past 20 years sewers have been constructed on curves, both horizontally and vertically, where this has appeared to be desirable. The minimum radius permitted depends on the diameter of pipe, length of pipe and type of joint but is never lower than 100 ft radius. In extreme cases the length of pipe is limited and the pipe has to be cut at an angle. Only one simple curve is permitted between manholes on sewers 27 in diameter or less. Curved sewers are considered to have been satisfactory. Sewers are designed on the basis of a domestic flow of 85 (U.S.) gallons per head per day and industrial flows of 0·008 cu ft per second per acre. A conservative value of the coefficient of friction is adopted in hydraulic design to cover variations in the field; 0·014 being used for all pipes of 17 in diameter and larger and 0·015 for smaller pipes regardless of material. The minimum size of sewer is 8 in diameter. Sewers 15 in diameter and smaller are designed to flow at ½ depth and those 18 in and above at ¾ depth with a minimum velocity of 2 ft/s. On large reinforced concrete sewers with a plastics lining it has been found necessary to limit the peak velocity to 12 ft/s to avoid damage to the lining. Brick manholes ranging from 4 ft diameter up to 5 ft 6 in diameter for 33 in diameter sewers are used. For larger sewers reinforced concrete manholes with plastics lining and clay pipe shafts have been developed. For sewers 7 to 21 in diameter the maximum distance between manholes is 400 ft, for sewers 24 to 30 in diameter it is 700 ft, and for those over 30 in diameter it is 900 ft. On large sewers manholes are placed at the beginning and end of all curves. Inverted siphons are avoided wherever possible. Where siphons are unavoidable adequate scouring velocity must be maintained for several hours per day, the rising slope of the down-stream leg is limited to 15% and sufficient number of barrels are provided to ensure flexibility under varying flow conditions. Drop manholes have a drop pipe one size larger than the inlet pipe. Bedding is selected from a chart giving 4 standardised types of bedding depending on the size of pipe and the depth of sewer. Beddings range from a layer of sand or fine crushed aggregate to complete encasement in 5 in of concrete. Complete surround may also be specified where a sewer is to be laid under a railway, right of way or where it lies within the pressure area of footings. Where sewers are to be constructed above or near existing sewers the latter are protected with a concrete blanket for the full width of the excavation. Special compaction is required where the sewer lies within unconsolidated fill and where the trench lies within the pressure zone of the footings. Special compaction is also considered where the sewer is close to the top of natural or man-made slopes and there is any possibility of slippage. Connections to sewers are made by drilling a core, in a single operation if the pipe is 18 in diameter or less, or in a series of 4 in holes if the opening is large. The opening is placed as low as possible to minimise the cascade of the sewage during periods of low flow and high enough to allow the contractor time during low flow to seal the pipe. If the sewer is brick or brick-concrete or unreinforced concrete it is uncovered symmetrically to avoid eccentric loading.

A176. The structural design of sewers is based, almost exclusively, on the work of Marston and Spangler. Limited research has been carried out to check both the accuracy of the Marston theory for the calculation of loads, and soil pressure on rigid and flexible pipes. Tests have been carried out to compare various granular beddings.

A177. The United States Department of the Interior are conducting laboratory tests at Denver and propose conducting field tests on 18 in to 30 in and 48 in diameter pipes. The work includes evaluation of reinforced plastic mortar pipes, a composite built from polyester resin, sand and glass fibre, the glass fibre reinforcement combining with the resin-sand mortar. The pipe is built up in layers on a mandrel in 20 ft lengths with sockets and spigots for rubber ring joints. The pipes were first developed by the United Technology Centre, California and are called 'Techite', being available in 4 classes and 8 to 48 in diameters. Larger sizes are planned. The material is claimed to have high strength to weight ratio, good chemical resistance and flexibility. Wet strengths are likely to be less than dry strengths and there will be losses in strength due to age and environment or because of fatigue under cycling stresses. Creep and crazing with weeping are likely to occur above a certain stress level. Laboratory tests include evaluation of physical properties after exposure, correlation of large with small pipes, examination of stiffness data and soil box tests.

South America

Argentine

A178. The Ministry of Public Works have published a number of official specifications.

A179. Vitrified clay pipes vary in diameter from 100 to 350 mm and in length from 0·610 to 0·762 m. 45° bends, tees and sockets are detailed.

A180. Plain concrete pipes are specified in diameters from 65 mm to 1000 mm, the minimum length varying from 0·6 to 1·2 m. Right angle branches have very short branches, the inside of the branch socket being as little as 25 mm from the inside of the pipe barrel in the smallest pipes. Alternatively a short socket piece may be set into the pipe in cement mortar. 45° branches are similar in that they have short branches or short socket pieces set in mortar. 45° bends have radii varying from 225 mm for 65 mm pipes to 900 mm for 500 mm diameter pipes. 90° bends have radii varying from 225 mm for 65 mm pipes to 300 mm for 500 mm diameter pipes. 90° elbows have radii of 100 mm for 65 mm diameter pipes rising to 200 mm for 150 mm diameter pipes. There are also elbows with bases; some of the elbows have tapers. Duckfoot bends have a hollowed pedestal. Tapers for 100 and 130 mm diameter pipes have a flat invert. Pipes, Y's and T's are manufactured with inspection covers. Pipes are tested by crushing with the loading applied at one point on the crown and the pipe supported at 2 points at the invert, or by the load being spread over 90° and the pipe supported over 90°. Reinforced concrete pipes are specified for diameters from 300 to 1000 mm. Absorption is limited to 8 %. The core pipe of a non prestressed pipe is regarded as being in compression, the mortar covering being in tension. Prestressed pipes have transverse and longitudinal pre-compression. Pipes subjected simultaneously to normal forces and oval deflection are designed on the basis of Schlick's experiments.

A181. Asbestos cement pipes are used up to 300 mm diameter and to stand an internal pressure test of 1·5 kgf/cm². Breaking loads and testing loads are specified for both 3 edge bearing and sand bearing tests. Rubber joint rings are used. Joints between asbestos cement pipes and couplings of clay or concrete, are made with yarn and cement mortar to centre the pipes.

A182. Pipes are laid on the excavated trench bottom with recesses for joints. Cast iron pipes are normally jointed with lead but may be jointed with mastic asphalt. They are subjected to a hydraulic test of 6 kgf/cm² for 10 minutes. Steel pipes are laid and tested in a similar manner. Clay pipes are laid on the trench bottom or a concrete bed. They are jointed with mastic asphalt and subjected to a hydrostatic pressure test of 2 m for 10 minutes. Trenches are backfilled with the pipes full of water at the test pressure while the first 600 mm of backfill is placed. Concrete pipes are jointed with mastic asphalt or, if the joint cannot be kept dry, with cement mortar. Care is taken to level the inverts of pipes and make good any irregularities. Non pressure pipes are subjected to a hydrostatic pressure test of 2 m above the highest pipe for a period of 2 hours for cement mortar joints and 4 hours for asphalt joints, subject to a maximum of 4 m above the lowest pipe. The permissible loss is specified in litres per 100 m per hour for various pipe diameters. A further test is carried out after backfilling. Defective joints or pipes are repaired with a 10 to 100 mm thick concrete ring. Pipes up to 300 mm diameter are usually thrust bored under paving using concrete, clay or

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asbestos cement pipes, with rubber ring joints. Tunnelling is also used to avoid disturbing the paving, the surround of the tunnel being completed by grouting from the surface. Backfilling of trenches up to 300 mm above the pipe is carried out by hand.

A183. The Public Works Department have considered the stresses in prestressed concrete pipes and regard it as most important that the mortar protecting the steel should not be overstressed. A comparison has been made of pipes made in two stages, i.e. with a concrete core and a mortar coating applied subsequently, and those made in one stage in which the prestressing is obtained by expanding the internal mould before the concrete has set.

Brazil

A184. Public sewers are constructed of vitrified clay or concrete pipes. A large proportion of new houses, however, drain to tanks which are considered in Brazil to solve the problem of sewage disposal in permeable soils.

Colombia

A185. Information has been obtained from the towns of Bogota and Medellin.

Bogota

A186. Foul sewers have to have at least 1 m cover. Pipes between 8 in and 16 in diameter are of vitrified clay; 16 in and 21 in of vitrified clay or concrete (plain or reinforced); 24 in to 30 in of vitrified clay or reinforced concrete; over 30 in of reinforced concrete. Trench loads, surcharge loads and the condition of the bedding are taken into account in design. Preference is given to pipes with rubber ring joints. Surface water sewers or combined sewers from 12 in to 18 in diameter are of vitrified clay, from 18 in to 30 in of vitrified clay or concrete and those above 36 in and up to 60 in of reinforced concrete. Concrete and clay pipes are generally 0·9 m long. Concrete pipes have to comply with an absorption limit of 8%. Large circular sewers may be formed of in-situ concrete lined with brickwork. Some large sewers have semi-circular roofs, 5% sloping inverts and are lined with brickwork, the roof having two courses of brickwork. Smaller pipes are bedded on a rectangular block of 1:3:5 concrete up to a third or a half of their depth. The larger sewers are laid on, surrounded and backfilled with selected fill in compacted 0·45 m layers. Circular manholes are, 1·2 to 1·5 m diameter, constructed of concrete sections or cast in-situ. Other manholes are constructed of tapered blocks or brickwork. The benching slopes upwards at an angle of 15° from the soffit of the pipe. Walls and base are of 1:3:5 concrete. Tops of walls may taper to the access or continue vertically to a flat 1:2:3 concrete roof.

Medellin

A187. Pipes have a minimum diameter of 8 in, pipes smaller than 30 in diameter being circular. Other shapes are permitted over 30 in diameter provided the pipe does not have a flat invert. Sewers are not laid in the same trenches as water mains. Trench widths for pipes up to 1800 mm diameter are specified. Timbering is used and trenches are drained where necessary. Backfilling is in 0·30 m layers, both sides of the pipe being well rammed at the same time. Spigot and socket pipes with rubber rings are used and holes are cut in the trench bottom for sockets. If the ground is good the bottom of the trench is cut to the shape of the pipe. In streets with foul and surface water sewerage the surface water sewers generally have a minimum cover of 1·2 m and foul sewers a minimum cover of 1·6 m. Combined sewers generally have a minimum cover of 1·6 m. If it is impossible to obtain 1 m of cover the pipes are surrounded with concrete. Pipes are not permitted with less than 0·6 m cover. Pipes are laid up to 5 m deep provided adjacent buildings are protected from structural damage. Foul sewers are laid below surface water sewers where they cross.

A188. Parameters for the hydraulic design of foul and surface water sewers including quantities of sewage, both domestic and industrial and of infiltration, are laid down in Medellin. Surface water sewers are designed by the rational method.

Sewage flows are based on:

domestic sewage	poor district	120–160 pints per house per day;
	middle class district	180–240 pints per house per day;
	high class district	250–290 pints per house per day;
industrial waste	undeveloped areas	0·4 pints per hectare per second;
	developed areas	actual flows;
infiltration	0·1 pint per hectare per second	

For hydraulic calculation Manning's formula is used with the following roughness coefficients:

vitrified clay	0·013
mortar or smooth concrete	0·013
concrete pipes	0·013
channels of smooth concrete	0·016
channels of rough concrete	0·025
earth channels with grass	0·050

Sewers are designed for the following minimum velocities:

normal flow	0·40 m/s;
pipe full	0·60 m/s for foul sewage;
pipe full	0·75 m/s for storm sewage

and the following maximum velocities for full pipes:

3·0 m/s for storm sewage;
4·0 m/s for foul sewage.

If the pipe is surrounded in concrete these values can be increased to 5·0 m/s. Velocities in concrete channels are not allowed to exceed 7·5 m/s with the channel flowing full. Maximum and minimum gradients and depths are stipulated.

West Indies

Jamaica

A189. Sewers are laid under the centre of roads with normal minimum depths to invert of 5 ft 6 in and have a minimum diameter of 7 in. Laterals are usually 4 in diameter and, unless the sewer is more than 9 ft deep, are connected to the sewer by means of a 45° angle branch and bend, the lateral being laid at a slope of 1 in 30. If the sewer is more than 9 ft deep the lateral is connected by a vertical riser surrounded in concrete. Laterals have a minimum depth of 3 ft 6 in at the property boundary. Sewers shallower than 4 ft cover and deeper than 14 ft cover are surrounded in 1:3:6 concrete. Clayware sewers to BS 65 are normally used but asbestos cement pipes are also used. Where asbestos cement pipes are laid at normal depths in fine grained soil the bottom of the trench is loosened for a depth of 3 in and lightly tamped, or 3 in of sand is spread and lightly tamped. In stony or rocky ground the bottom of the trench is covered with 6 in of sand. The pipe is then covered to a height of 12 in with sand or sieved soil. Manholes are provided at all changes of direction and at spacings not greater than 300 ft.

Trinidad

A190. Many materials are required to comply with American specifications. Concrete pipes are made with sulphate resisting cement and absorption must not exceed 6% of the dry weight of the pipe. Pipes are used in the following lengths:

diameter	lengths
4 in and 6 in	2½ ft to 5 ft
8 in and 10 in	3 ft to 6 ft
12 in, 15 in and 18 in	4 ft to 8 ft
over 18 in	6 ft to 16 ft

Trenches for pipes laid in gravel bedding or with concrete cradle may be excavated by machinery. Those for pipes to be laid on the trench bottom must be completed by hand. Pipe trenches have to be kept as narrow as possible and must have vertical sides up to 1 ft above the top of the pipe. Backfill around pipes is compacted by tamping and the remainder by water jetting, puddling or tamping in layers not exceeding 12 in thick. Tamping is only used above the pipe surround if the material is unsuitable for jetting or puddling. Pipes bedded in screened gravel are not otherwise supported. Those bedded or surrounded with concrete are supported on concrete blocks or precast concrete saddles. Selected granular material consists of stone, gravel and sand or finely divided mineral matter complying with a specified grading such that it all passes through a 1½ in sieve. It is spread in layers not thicker than 6 in.

A191. Manholes are constructed of concrete, brickwork, masonry or precast reinforced concrete sections. Mortar for masonry consists of cement, lime and sand such that the volume of sand shall not exceed 3 times the volume of cement and lime. Outside faces of masonry are rendered with mortar ½ in to ⅝ in thick. Sulphate resisting cement is used for manhole construction. Pipes are tested with water to 2 ft above the top of the sewer at its upper end.

Federation of Malaysia

Malaysia

A192. Sewerage is the responsibility of local town and municipal authorities but only two towns, George Town, and Kuala Lumpur, have installed sewerage systems of any extent.

A193. In George Town sewers are constructed of glazed stoneware, pitch fibre and cast iron pipes from 6 in to 15 in diameter. Spigot and socket stoneware pipes are manufactured locally in 2 to 3 ft lengths. They are laid on 4 in of

1:3:6 concrete, haunched or surrounded, where the cover is less than 3 ft. They are designed to have a self cleansing velocity with a maximum velocity of 8 ft/s. Six inch diameter pitch fibre pipes in 8 to 10 ft lengths are laid without any concrete foundation or haunching. Although more expensive they are used as they are easier to lay than stoneware pipes. They are normally used in filled areas but it has been found that they tend to flatten under uneven pressure and have a short life. Their use is also limited by the fact that only 6 in diameter pipes are available. Cast iron pipes are used for all road, drain or stream crossings. Spun reinforced concrete pipes, from 18 ins diameter to 72 ins diameter, manufactured locally to Australian Standard Specification A35/1957 and British Standard Specification 556/1955, are now being laid.

A194. The Municipality of Kuala Lumpur requires foul drains and private sewers to be constructed of glazed stoneware, cast iron, concrete or asbestos cement pipes. The pipes, minimum diameter 4 in, have to be laid to falls of at least 1 in 60 for 4 in diameter pipes, 1 in 80 for 6 in diameter pipes and 1 in 100 for 9 in diameter pipes. Pipes within 50 ft of buildings are constructed of cast iron or on a bed of concrete carried half-way up the pipe. Manholes are provided at every change of direction and gradient and are constructed of brickwork or precast concrete. British Standards, including Code of Practice 2005, are followed.

Singapore

A195. The Public Works Department specification requires all materials to comply with the appropriate British Standard. Concrete pipes with a ½ in minimum thickness high alumina cement mortar lining comply with BS 556. Two pipes from each batch of 50 are jointed and submitted to a water test of not less than 20 lbf/in², for a period of 30 seconds. Sulphate resisting cement pipes comply with similar requirements but an additional ¾ in has to be added to the internal surface of the pipe over the cover laid down in Australian standard No A35. The load test requirements are also increased by 10%. Pvc lined concrete pipes comply with the general clauses for concrete pipes. The lining is not less than 0·06 in thick, formed with mechanical keys into the concrete and covers not less than 270° of the internal circumference. The pvc is specified in detail. The keys are continuous and capable of standing a back pressure of 70 lbf/in². Asbestos cement pipes to BS 486 and gvc pipes to BS 65 are used. The latter are specified with rubber or polyester ring joints. Pitch fibre, cast iron, spun iron and steel pipes are to the appropriate BS.

A196. Refilling of trenches is with selected hard dry material free from larger stones placed in layers of 6 in, up to 12 in over the pipe. The remainder of the backfill has to be placed in layers not more than 24 in deep. One man is employed ramming backfill for every man refilling for the first 12 in over the top of the pipe. Bakau (timber) piling or, in extreme conditions, concrete piling are used to support structures in poor ground. Curved pipelines are permitted, use being made of standard pipe lengths wherever possible. 1:2:4 concrete is used for bedding, haunching and surround and is broken every 4 pipes or 20 ft, whichever is the less, by a 1 in thick board placed vertically and left in position. Pipes supported on granular material have timber blocks and wedges to support them. Pipes in tunnels are bedded on concrete and the heading packed solidly with concrete.

A197. The pvc of lined concrete pipes is thermo-welded across pipe joints. Clayware pipes are jointed with tarred gaskin and 1:3 cement mortar. Asbestos cement pipes are jointed with detachable cast iron, steel or asbestos cement joints. Steel pipes over 33 in diameter are welded internally and externally. The joints are tested by applying a pressure of 75 lbf/in^2 for at least 10 minutes between the welds. Smaller pipes welded externally are tested as cast iron and asbestos cement pipes. Surface water channels around buildings and outfall drains are constructed of 1:2:4 concrete. Channels have a minimum depth of 6 in and falls not less than 1 in 180.

A198. Sewers of 21 in and less in diameter are tested with a hydrostatic head of 4 ft for 30 minutes, before being surrounded. Testing of some pipelines may be effected by an air test with a pressure equal to 1 in of water. Sewers over 21 in are inspected but not tested. Cast iron, steel and asbestos cement pressure pipelines of 24 in diameter or less are tested hydrostatically for 30 minutes with the trench partially backfilled. A loss of less than one pint per inch of diameter per mile of pipeline is considered satisfactory.

A199. Manholes are cast in-situ using a 1:2:4 mix concrete or reinforced concrete tubes, both types being made with sulphate resisting cement. Chamber and shaft rings have effective lengths of 2, 3 and 5 ft and tapers a length of 2 ft. Slabs and shafts are set in sulphate resisting cement mortar. Channels and benching, of manholes or sewers up to 24 in diameter, are formed of sulphate resisting cement granolithic concrete. In larger sewers the benching and channels of manholes are formed of concrete finished with a 3 in thick layer of sulphate resisting cement.

Central Africa

Zambia

A200. Sewerage is the responsibility of the various town councils and the Republic's Works Department. United Kingdom practice is followed. Formation of hydrogen sulphide resulting in sulphuric acid attack on concrete pipes is a problem due to the higher temperatures but corrosion from the acid is minimised by the use of calcareous (dolomite) aggregate. The Works Department construct sewers for institutions or small rural towns, but these do not exceed 9 in diameter. Salt glazed earthenware pipes are normally used from buildings to the manhole on the sewer and asbestos cement pipes in the sewerage system. As it has been difficult to obtain asbestos-cement pipes due to sanctions on Rhodesia, pitch fibre, concrete and earthenware pipes have been used for the main sewers. Salt glazed earthenware and concrete pipes are manufactured locally in limited quantities. Earthenware pipes are produced with a rigid joint but the manufacturer intends producing a flexible joint. A local firm has acquired an agency for pvc sewer pipes and it is proposed to consider their suitability in this climate. Pipes and fittings of glazed earthenware, cast iron, pitch fibre and concrete are required to comply with the appropriate British Standard. Asbestos cement pipes have to be seamless, free from defects, concentric and comply with specified tolerances regarding diameter. Pipes are manufactured in standard lengths of 13 ft 1½ in and to have a maximum deviation from a straight line of ⅝ in.

A201. The Department's specification specifies the trench width at the crown of the pipe and requires excess excavation for rigid jointed sewers to be backfilled with 1:3:6 concrete and that for mechanical jointed sewers to be filled in with selected material well watered. Where concrete protection is not required the pipes are bedded on a 3 in thick bed of selected gravel free from vegetable matter, all of the gravel passing a $\frac{3}{4}$ in ring. The bed is well watered and compacted. The use of bricks to support pipes during laying is not permitted. Concrete protection consists of a bed of selected material, a 2 in thick blinding layer of 1:5:10 ($\frac{3}{4}$ in) concrete and a surround of 1:3:6 ($\frac{3}{4}$ in) concrete. The surround is 3 in thick below the pipe, extends the full width of the trench and is haunched over the pipe to give a minimum thickness of 4 in. A 4 in gap is left in the concrete protection at each pipe joint and a similar gap left in the blinding concrete before hardening. Horizontal and vertical joints are not permitted in any concrete protection or surround. Concrete protection is required where pipes pass under buildings, pass under roads with less than 4 ft of cover, have less than 2 ft of cover or have cover greater than 14 ft. Backfilling is with selected material passing a $\frac{3}{4}$ in diameter ring in 3 to 6 in layers for a minimum of 12 in above the pipe or concrete surround and then in 6 in layers. Each layer is well watered and consolidated. Pipes are tested by passing a ball $\frac{1}{4}$ in less than the pipe diameter and by applying a hydrostatic pressure test of 5 to 10 ft before backfilling. The pipes have to withstand the test for 10 minutes, allowance being made for absorption. An air test of a pressure of 1 in of water is applied and maintained for 5 minutes after backfilling.

A202. Manholes are usually constructed in brickwork on a concrete base. Bricks have an average crushing strength of 2750 lbf/in^2 and a water absorption limit of 7·5%. Invert channels up to 6 in diameter are glazed earthenware and larger channels are formed in concrete. Benching is carried up vertically to soffit level and then sloped up at 20°. Brickwork is arched over all pipes greater than 6 in diameter. Flexible joints are provided in every drain or sewer where they are connected to manholes, the joint being not further than 12 in from the manhole wall. Manholes may be constructed with precast concrete rings. These are supported on a concrete wall at least 6 in above the crown of the highest connection. Brick manholes are rendered in 3:1 mortar applied in one coat up to $\frac{3}{4}$ in thick.

West Africa

Ghana

A203. Designs are based on British practice. Existing installations are however small. The main sewerage of Accra is planned to commence in the near future. The draft general specification of the Public Works Department lists pitch fibre, salt glazed clayware, asbestos cement pressure, concrete, cast iron, spun iron and steel pipes to the appropriate British Standard for sewers. Clayware pipes and porous concrete pipes to British Standard are permitted for field drains. Manholes are constructed of precast concrete sections in accordance with BS 556. Excess excavation is filled with 1:4:8 concrete, sand or gravel. Backfilling up to 12 in above tops of pipes is with selected material placed and rammed in 3 in layers on the sides of the pipes and in 6 in layers lightly tamped above the pipe. The remaining backfill is in 12 in layers. Concrete bed, haunching and surround of 1:3:6 (1 in aggregate) concrete is used where specifically directed. Where salt glazed pipes are haunched the concrete is carried up for the full width of the bed to the level of the horizontal diameter and splayed from this level to meet the pipe tangentially. With cast iron, steel or concrete pipes the concrete is carried up from the outside edge of the bed to meet the pipe barrel tangentially. Pipes surrounded with concrete have a minimum of 6 in of concrete over the pipe barrel. Salt glazed pipes are jointed with a hemp gasket followed by 1:1 cement/sand mortar. Bitumen jointing is used as an alternative. Asbestos cement pressure pipes are jointed with cast iron detachable joints or with screw joints. Concrete spigot and socket pipes are jointed in a similar way to salt glazed clayware pipes. Collar joints have a gasket of hemp or jute dipped in hot bitumen and 1:1½ cement/sand mortar. Pipes are tested with water before haunching or surround and the test is repeated after backfilling. A minimum test pressure of 5 ft of water is applied. An air pressure test equal to 4 in of water may be used, the pressure not falling below 3 in of water during a 5 minute period. Steel, cast iron and asbestos cement pipes required to work under pressure are tested by hydraulic pressure to 50% above the expected working pressure or 60 lbf/in^2 if greater. The maximum permissible leakage is one gallon of water per inch diameter of pipe, per mile, per day, per 100 ft head of test pressure.

Japan and Hong Kong

Hong Kong

A204. The Public Works Department's specification requires clay, cast iron and pvc pipes to comply with the relevant British Standard Specification. Clayware pipes are normally used for sewers less than 24 in diameter and precast concrete or in-situ concrete pipes for larger diameters. Precast concrete pipes are specified to have an aggregate of maximum size 1 in, or the depth of cover to any reinforcement, or ¾ of the minimum distance between any circumferential reinforcement, whichever is the least. Elliptically reinforced pipes are specified. Joints may be spigot and socket, rebated, butt-ended with precast reinforced concrete collars, butt ended in-situ concrete collars or of the flexible type. Pipes have to stand a hydrostatic pressure test of 10 lbf/in^2 for a period of 2 minutes. One pipe in 50 is required to stand a non-destructive strength test, i.e. cracking load for reinforced pipes and proof load for unreinforced pipes. Dimensions and tolerances are listed for reinforced concrete pipes from 6 to 102 in diameter and for unreinforced pipes up to 30 in diameter. Required minimum strength for cracking load and ultimate load in lbs per ft effective length are listed for reinforced, extra strength reinforced and special strength reinforced pipes. Proof load and ultimate load are listed for unreinforced pipes. Most sewers are laid in trenches but some pipes are laid on the surface of the ground and covered with earth. Pipes are bedded and surrounded with concrete. Rubber ring joints have sometimes been used for small diameter pipes in newly reclaimed areas where settlement is expected. Pipes are supported behind the socket, clear of the trench bottom, on concrete blocks or cradles padded with roofing felt. For pipes of 27 in diameter and above a similar block is placed near the spigot end. Larger diameter pipes are usually supported on reinforced concrete piles but a mechanical joint has also been tried to provide flexibility. Pipes up to 30 in diameter are tested for watertightness after jointing and before backfilling or concreting.

Japan

A205. The Japan Sewage Works' Association have published booklets entitled: *Design criteria for sewerage and sewage purification;*

Reinforced concrete pipes for sewers;
Laying and constructing sewer pipes;
Experimental study of loads on buried pipes; and
Criteria for tunnelling shields for sewers.

There are standards for centrifugal reinforced concrete pipes and rolled reinforced concrete pipes.

A206. The standard for centrifugal reinforced concrete pipes covers plain pipes from 75 to 1800 mm diameter, socket and spigot pipes from 75 to 900 mm diameter and ogee pipes from 900 to 1800 mm diameter. The pipes are 2 or 2·43 m long, half lengths being manufactured if necessary. The pipes have to comply with an external load crushing test of 1300 to 3800 kgf/m against cracking and 2000 to 11,300 kgf/m against breakage, the lowest values applying to pipes 250 mm diameter and the highest values to those of 1800 mm diameter. Pressure pipes are tested to stand a hydrostatic test pressure varying from 1 to 10 kgf/cm^2 depending on the class.

A207. The standard for rolled reinforced concrete pipes covers plain pipes and collars from 150 to 1800 mm diameter, socket and spigot pipes from 150 to 1800 mm diameter and ogee pipes from 900 to 1800 mm diameter. The pipes are 2 or 4 m in length, half lengths being manufactured if necessary. The pipes have to withstand an external loading test of 1300 to 3800 kgf/m against cracking and 2000 to 11,300 kgf/m against breaking, the lowest values applying to pipes of 250 mm diameter and the highest values to those of 1800 mm diameter. Pressure pipes are tested to stand a hydrostatic test pressure varying from 1 to 6 kgf/cm^2.

A208. The Association's specification covers reinforced concrete pipes from 100 to 2400 mm diameter. These include plain pipes and collars 1000 to 2400 mm diameter, socket and spigot pipes from 1000 to 2000 mm diameter and ogee jointed pipes from 100 to 2400 mm diameter. Lengths for the first two are 2·43 m and for the third 2·36 m. Pipes have to comply with an external load test of 5600 to 8800 kgf/m against cracking and 11,200 to 17,600 kgf/m against breaking.

A209. The need to bear the soil characteristics in mind in design and to carry out a survey is emphasised. The allowable load on the soil is determined if possible by load testing or core boring, bearing in mind certain standard values. Load tests are carried out on areas of about 0·75 sq m. If the soil is likely to freeze it may be replaced with a soil which is less susceptible to frost or the subsoil water may be pumped out. In poor soils pile driving is used and any wooden piling is placed so that it is below the water surface to prevent deterioration from alternate drying and soaking. The allowable bearing strength is found by dividing the limiting bearing strength by a safety factory between 2 and 4. Trench excavation is facilitated by the use of wellpoints, freezing and sheet piling. Attention is paid to timbering of trenches to protect adjacent structures. Concrete sleeper, open web timber and concrete foundations are used. Sewers are frequently constructed of segmental sections in tunnels using shields. It is, however, realised that accurate design calculations are then more difficult because of lack of knowledge of ground conditions. Ground pressure is regarded as consisting of primary ground pressure, i.e. the pressure force on the undisturbed natural ground prior to making a tunnel; and secondary pressure, i.e. the pressure after displacement at the excavation face or the structure adjacent to it by the shield. It is considered that there is little variation in primary or secondary pressures at the shield, but the secondary pressure on the segment is different from the primary because of the gap left by the shield's tail.

India

A210. There are standards for salt glazed stoneware pipes, asbestos cement non-pressure pipes, asbestos cement pressure pipes, concrete pipes plain and reinforced, prestressed reinforced concrete pipes and steel cylinder reinforced concrete pipes. There are codes of practice for laying cast iron pipes, for laying concrete pipes and for constructing manholes, flushing tanks and inverted syphons.

A211. In 1965 the specification for salt glazed stoneware pipes and fittings was revised to include a crushing strength test and performance values. The crushing strength test was not made mandatory as equipment was not widely available.

The standard covers:

straight pipes 100 to 600 mm diameter in 50 mm steps excluding 550 mm; length 0·6 m (or 0·75 m for 200, 250 and 300 mm diameter); tapers; $\frac{1}{4}$, $\frac{1}{8}$ and $\frac{1}{16}$ bends; $\frac{1}{4}$ and $\frac{1}{8}$ taper bends; and 45° or 90° junctions.

Pipes have to withstand a hydraulic test of 1·5 kgf/cm^2 and fittings a test of 0·75 kgf/cm^2. Absorption tests, acid resistance and resistance to magnesium sulphate are specified. The crushing strength test requires the pipes to have a minimum crushing strength of 1600 kgf/m length when tested by a 3 edge bearing test.

A212. Steel cylinder reinforced concrete pipes consist of steel cylinders, 3·15 to 10 mm thick surrounded internally and externally by reinforced concrete. The internal reinforced concrete is always placed at the works, but the external reinforced concrete is placed either at the works or on site. The pipe diameters vary from 200 to 1800 mm and there are 5 classes ranging from 50 m to 250 m head.

A213. The standard for concrete pipes covers both non-pressure and pressure pipes. Unreinforced non-pressure pipes 1 m long are listed in diameters from 80 to 450 mm. Reinforced concrete non-pressure pipes are listed as light duty 80 to 1800 mm diameter in lengths of 2·0 m (up to 400 mm diameter), 2·5 and 3 m (from 300 mm diameter upwards) or heavy duty from 350 to 1200 mm diameter in lengths of 2·5 and 3 m. Concrete pipes have to withstand a three edge bearing test or a sand bearing test in which no crack greater than 0·25 mm should appear when the test load is applied to reinforced pipes. Unreinforced and reinforced pipes also have to comply with an absorption test limiting their absorption to 2·5% in 10 minutes and to 6·5% in 24 hours and be capable of withstanding a hydrostatic pressure test of 7 m. The ends of all pipes are suitable for butt end joints except that unreinforced pipes may have spigot and socket joints. The butt ends may be prepared for a collar or internal flush joint. Bends, junctions and specials are generally of cast iron or steel.

A214. Reinforced concrete pressure pipes are specified for:

(a) diameters 80 to 1200 mm for 2 kgf/cm^2 pressure test; in lengths 2·0 m (up to 350 mm diameter) 2·5 m and 3·0 m (from 300 mm diameter upwards);

(b) diameters 80 to 600 mm for 4 kgf/cm² pressure test; in lengths 2·0 m (up to 350 mm diameter) 2·5 m and 3·0 m (from 300 mm diameter upwards); and

(c) diameters 80 to 400 mm for 6 kgf/cm² pressure test; in lengths 2·0 m (all sizes) 2·5 and 3·0 m (from 300 mm diameter upwards).

Strength requirements for these pressure pipes are the same as for heavy duty non-pressure pipes.

A215. Asbestos cement pressure pipes have been used since 1935 although most of these have been imported. The standard covers pipes of diameter 50, 80, 100, 125, 150, 200, 250, 300, 450, 600, 900 and 1000 mm in lengths of 3 m for diameters of 100 mm or less and 4 m for diameters greater than 100 mm. The test pressures are listed as 5, 10, 15, 20 and 25 kgf/cm² (165, 330, 495, 660 and 828 ft head). A transverse crushing stress test is detailed in which the unit stress for transverse crushing has to be not less than 450 kgf/cm.

A216. A standard for prestressed pipes was issued in 1959. It covers pipes from 80 to 400 mm diameter in 2 m lengths and from 450 to 1800 mm diameter in 2·5 m lengths. Three edge bearing test and sand bearing test strength requirements are listed.

A217. The code of practice for laying concrete pipes, published in 1959, outlines methods for calculating loads on pipes and their supporting strength, also methods of handling, laying and jointing pipes. It is based on bulletins of the Iowa Engineering Experimental Station. Pipes should not be bedded on the trench bottom unless it has been suitably rounded for 60° to 90° of the circumference, i.e. a bearing width of at least half the diameter. Tables and charts show:

(a) the coefficients for H/Bt for different soils;

(b) width of trench/width of pipe ratios at which loads are equal by both the trench formula and the culvert formula;

(c) the coefficients for negative projecting pipes and imperfect trench conditions; and

(d) influence coefficients for rectangular areas.

Concrete cradle bedding should be at least ¼ of the diameter of the pipe thick, subject to a minimum of 100 mm and a maximum of 300 mm. The concrete should extend up the sides of the pipe for a minimum depth of ¼ of the outside diameter. Trenches should be backfilled to a depth of 300 mm immediately after a pipe has been laid. It is preferred that pipes under embankments be laid with a projection ratio not greater than 0·7. Attention is drawn to the possible detrimental effect of a concrete cradle in that it will, in extreme cases, increase the settlement ratio and increase the load. For pipes 600 mm or less in diameter in an embankment it is recommended that the embankment be constructed 150 mm above the level proposed for the top of the pipe and the trench excavated therein. Similar methods are proposed for the construction of pipes in very high embankments. The following joints are approved:

(a) bandage joint—an on-site collar type joint of mortar, netting and scrim;

(b) spigot and socket joint, either rigid with 1:2 cement mortar or semi-flexible with a rubber ring;

(c) collar joint, rigid or semi-flexible; and

(d) flush joint filled with cement mortar on the internal or external face.

The recess at the ends of the pipes of pressure pipelines is filled with jute braiding soaked in bitumen and the pipes jacked together. For non-pressure pipelines the recess is filled with cement mortar. Before testing a pipeline is filled with water for a week. The actual test lasts an hour and a seepage of 2·5 litres per kilometre per hour per centimetre diameter is permitted.

A218. The code of practice for cast iron pipes recommends a minimum cover of 900 mm under roads. The width of the bottom of the trench should provide not less than 200 mm clearance on either side of the pipe. Rocks, boulders or large stones should be removed if within 150 mm of pipes up to 600 mm diameter and 200 mm of larger pipes. Backfill up to the centre line of the pipe should be sand or gravel in 80 mm layers.

A219. The code of practice for manholes states that they should be provided at every change of alignment or gradient of sewers, at every junction of two or more sewers, at the head of all sewers and branches, wherever there is a change in size of sewer, and at regular intervals in the sewerage system. The maximum spacing of manholes should be:

pipe diameter (mm)	spacing (m)
up to 300	45
301 to 500	75
501 to 900	90
over 900	depends on local conditions.

In the case of large sewers which a man can enter it is not considered essential to have a manhole at every change in alignment on curves up to 30°. Manholes should be sited at tangent points as it is easier to build a chamber on a straight sewer than on a curve. Some manhole chambers may be omitted in very large sewers in which a man can stand. The spacing of manholes on very large sewers is governed by:

(a) the distance which silt or other obstructions may have to be conveyed along the sewer to the nearest manhole for removal;

(b) the distance materials for repairs may have to be conveyed through the sewer; and

(c) ventilation requirements for men working in the sewer.

Shallow manholes, defined as less than 2 m deep, should be 1·2 m long and 0·75 m wide. Circular chambers should have a minimum diameter of 1·2 m. The minimum diameter of deep manholes should be 1·5 m. The width should be increased to provide sufficient benching on the sides to permit two men to work with their cleaning equipment. Circular access shafts may be provided on large sewers with a minimum internal diameter of 700 mm. Where the shaft depth exceeds 3 m the dimensions should be increased to facilitate cleaning and maintenance. Brickwork shafts are corbelled on 3 sides. Manhole walls are usually constructed of brickwork on a cement concrete foundation slab. They are rendered internally and externally and a brick relieving arch is built over the sewer pipe. Reinforced concrete manholes may be used where the sub-soil water is high. It is preferred that these be circular with reinforced concrete around the chamber up to ground water level. The benching should have a fall towards the invert of 1 in 12. Rungs in two vertical runs should be built in manholes over 0·8 m deep. Openings should be at least 500 mm diameter, circular covers being preferred. Rest chambers and safety chains are recommended for large sewers or deep chambers.

A220. Flushing tanks are recommended where the flow is never sufficient to fill half the pipe or to maintain a self-cleansing velocity. The approximate quantities of flushing water over a length of 75 to 90 m is:

diameter of pipe	flush
250 mm	1400 to 1700 litres
350 mm	1700 to 2700 litres
400 mm	2700 to 3600 litres
450 mm	3600 to 4500 litres

Flushing tanks are designed to operate once a day.

A221. The minimum desirable velocity in rising mains is considered to be 0·8 m/s. Pumping velocities in excess of 1·8 m/s are not recommended.

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DEPARTMENT OF THE ENVIRONMENT

Working Party on the Design and Construction of Underground Pipe Sewers

Third Report

LONDON
HER MAJESTY'S STATIONERY OFFICE
1971

The Working Party on the design and construction of underground pipe sewers was appointed by the Minister of Housing and Local Government in June 1964 with the following terms of reference:

> 'to investigate the practical application of structural theory to the design and construction of buried pipe sewers having due regard to structural stability, to watertightness and to economy in capital, operational and maintenance costs; to consider and advise on the relative merits of flexible and rigid construction over a range of ground and loading conditions commonly occurring in practice; and to initiate and co-ordinate research and experiment directed towards the production of reliable design data and the co-ordination of design and construction'.

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The following abbreviations have been used in this report.

in	inch, inches.	mm	millimetre.	l	litre.
ft	foot, feet.	cm	centimetre.	kg	kilogramme.
s	second.	m	metre.	kgf	kilogramme force.
lbf	pounds force.	km	kilometre.	N	newton.
				kN	kilonewton.
				daN	decanewton.

Quantities are in general given in metric units except that where information was received in imperial units these have usually been retained.

To the Right Honourable Peter Walker, M.B.E., M.P.,
Secretary of State for the Environment.

Sir,

1. Our first interim report, submitted in October 1965*, described the background to the setting up of the Working Party and gave an account of our activities from our formation in June 1964 up to that time. Our second report, submitted in May 1967, included a recommendation that a major programme of experimental research be carried out so that we might offer detailed advice on the structural design of sewers. We now have the honour to submit our third report.

2. We have met as a full Working Party on thirty-seven occasions. Since our last report we have visited construction sites and pipe manufacturing works of particular interest. Our research team leader has visited many laboratories to advise us on the best methods of carrying out our own research programme. Members of the Working Party have attended regular meetings of the panel directing the research. Our sub-committees have held sixty-five meetings.

3. We are dividing this report into three main sections. The first continues our considerations of the practical design and construction of sewers which formed part of our second report. The second section deals with foreign practice, and the third with the programme of research which we have been authorised to carry out. Finally the report concludes with a review of the position. It is emphasised that the three main sections are closely related. Our advice on design and construction depends to a considerable extent on research. As a result of our investigation of foreign practice, our own research and recommendations will be able to take cognizance of world wide experience. Our research is still at an early stage and we are not yet able to elaborate the recommendations on structural design given in our second report. The urgent need for information on our research and advice on its application is of course appreciated.

4. A revised edition of British Standard Code of Practice 2005, *Sewerage* was published in December 1968. The code outlines the rational method of structural design and details the traditional method. The timing of the publication of the Code prevented the inclusion of the recommendations contained in our second report, but the Code indicated that its next revision would deal with the subject more comprehensively.

5. We are pleased that *Simplified tables of external loads on buried pipelines*, replacing National Building Study Special Report 32, was published in 1970.

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*Published in 1966.